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# Appendices

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# Appendix A. Properties of Gases and Vapors

**TABLE A.1 Properties of Dry Air at Atmospheric Pressure**

## Symbols and Units:

$K$ = absolute temperature, degrees Kelvin
deg $C$ = temperature, degrees Celsius
deg $F$ = temperature, degrees Fahrenheit
$\rho$ = density, kg/m$^3$
$c_p$ = specific heat capacity, kJ/kg·K
$c_p/c_v$ = specific heat capacity ratio, dimensionless
$\mu$ = viscosity, N·s/m$^2$ × 10$^6$ (For N·s/m$^2$ (= kg/m·s) multiply tabulated values by 10$^{-6}$)
$k$ = thermal conductivity, W/m·k × 10$^3$ (For W/m·K multiply tabulated values by 10$^{-3}$)
$Pr$ = Prandtl number, dimensionless
$h$ = enthalpy, kJ/kg
$V_s$ = sound velocity, m/s

| *Temperature* | | | *Properties* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $K$ | *deg C* | *deg F* | $\rho$ | $c_p$ | $c_p/c_v$ | $\mu$ | $k$ | $Pr$ | $h$ | $V_s$ |
| 100 | −173.15 | −280 | 3.598 | 1.028 | | 6.929 | 9.248 | .770 | 98.42 | 198.4 |
| 110 | −163.15 | −262 | 3.256 | 1.022 | 1.420 2 | 7.633 | 10.15 | .768 | 108.7 | 208.7 |
| 120 | −153.15 | −244 | 2.975 | 1.017 | 1.416 6 | 8.319 | 11.05 | .766 | 118.8 | 218.4 |
| 130 | −143.15 | −226 | 2.740 | 1.014 | 1.413 9 | 8.990 | 11.94 | .763 | 129.0 | 227.6 |
| 140 | −133.15 | −208 | 2.540 | 1.012 | 1.411 9 | 9.646 | 12.84 | .761 | 139.1 | 236.4 |
| 150 | −123.15 | −190 | 2.367 | 1.010 | 1.410 2 | 10.28 | 13.73 | .758 | 149.2 | 245.0 |
| 160 | −113.15 | −172 | 2.217 | 1.009 | 1.408 9 | 10.91 | 14.61 | .754 | 159.4 | 253.2 |
| 170 | −103.15 | −154 | 2.085 | 1.008 | 1.407 9 | 11.52 | 15.49 | .750 | 169.4 | 261.0 |
| 180 | −93.15 | −136 | 1.968 | 1.007 | 1.407 1 | 12.12 | 16.37 | .746 | 179.5 | 268.7 |
| 190 | −83.15 | −118 | 1.863 | 1.007 | 1.406 4 | 12.71 | 17.23 | .743 | 189.6 | 276.2 |
| 200 | −73.15 | −100 | 1.769 | 1.006 | 1.405 7 | 13.28 | 18.09 | .739 | 199.7 | 283.4 |
| 205 | −68.15 | −91 | 1.726 | 1.006 | 1.405 5 | 13.56 | 18.52 | .738 | 204.7 | 286.9 |
| 210 | −63.15 | −82 | 1.684 | 1.006 | 1.405 3 | 13.85 | 18.94 | .736 | 209.7 | 290.5 |
| 215 | −58.15 | −73 | 1.646 | 1.006 | 1.405 0 | 14.12 | 19.36 | .734 | 214.8 | 293.9 |
| 220 | −53.15 | −64 | 1.607 | 1.006 | 1.404 8 | 14.40 | 19.78 | .732 | 219.8 | 297.4 |
| 225 | −48.15 | −55 | 1.572 | 1.006 | 1.404 6 | 14.67 | 20.20 | .731 | 224.8 | 300.8 |
| 230 | −43.15 | −46 | 1.537 | 1.006 | 1.404 4 | 14.94 | 20.62 | .729 | 229.8 | 304.1 |
| 235 | −38.15 | −37 | 1.505 | 1.006 | 1.404 2 | 15.20 | 21.04 | .727 | 234.9 | 307.4 |
| 240 | −33.15 | −28 | 1.473 | 1.005 | 1.404 0 | 15.47 | 21.45 | .725 | 239.9 | 310.6 |
| 245 | −28.15 | −19 | 1.443 | 1.005 | 1.403 8 | 15.73 | 21.86 | .724 | 244.9 | 313.8 |
| 250 | −23.15 | −10 | 1.413 | 1.005 | 1.403 6 | 15.99 | 22.27 | .722 | 250.0 | 317.1 |
| 255 | −18.15 | −1 | 1.386 | 1.005 | 1.403 4 | 16.25 | 22.68 | .721 | 255.0 | 320.2 |
| 260 | −13.15 | 8 | 1.359 | 1.005 | 1.403 2 | 16.50 | 23.08 | .719 | 260.0 | 323.4 |
| 265 | −8.15 | 17 | 1.333 | 1.005 | 1.403 0 | 16.75 | 23.48 | .717 | 265.0 | 326.5 |
| 270 | −3.15 | 26 | 1.308 | 1.006 | 1.402 9 | 17.00 | 23.88 | .716 | 270.1 | 329.6 |
| 275 | +1.85 | 35 | 1.285 | 1.006 | 1.402 6 | 17.26 | 24.28 | .715 | 275.1 | 332.6 |
| 280 | 6.85 | 44 | 1.261 | 1.006 | 1.402 4 | 17.50 | 24.67 | .713 | 280.1 | 335.6 |
| 285 | 11.85 | 53 | 1.240 | 1.006 | 1.402 2 | 17.74 | 25.06 | .711 | 285.1 | 338.5 |
| 290 | 16.85 | 62 | 1.218 | 1.006 | 1.402 0 | 17.98 | 25.47 | .710 | 290.2 | 341.5 |
| 295 | 21.85 | 71 | 1.197 | 1.006 | 1.401 8 | 18.22 | 25.85 | .709 | 295.2 | 344.4 |
| 300 | 26.85 | 80 | 1.177 | 1.006 | 1.401 7 | 18.46 | 26.24 | .708 | 300.2 | 347.3 |
| 305 | 31.85 | 89 | 1.158 | 1.006 | 1.401 5 | 18.70 | 26.63 | .707 | 305.3 | 350.2 |
| 310 | 36.85 | 98 | 1.139 | 1.007 | 1.401 3 | 18.93 | 27.01 | .705 | 310.3 | 353.1 |
| 315 | 41.85 | 107 | 1.121 | 1.007 | 1.401 0 | 19.15 | 27.40 | .704 | 315.3 | 355.8 |
| 320 | 46.85 | 116 | 1.103 | 1.007 | 1.400 8 | 19.39 | 27.78 | .703 | 320.4 | 358.7 |

*Condensed and computed from: "Tables of Thermal Properties of Gases", National Bureau of Standards Circular 564, U.S. Government Printing Office, November 1955.

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**TABLE A.1 (continued) Properties of Dry Air at Atmospheric Pressure**

| *Temperature* | | | *Properties* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *K* | *deg C* | *deg F* | $\rho$ | $c_p$ | $c_p/c_v$ | $\mu$ | $k$ | *Pr* | $h$ | $V_s$ |
| 325 | 51.85 | 125 | 1.086 | 1.008 | 1.400 6 | 19.63 | 28.15 | .702 | 325.4 | 361.4 |
| 330 | 56.85 | 134 | 1.070 | 1.008 | 1.400 4 | 19.85 | 28.53 | .701 | 330.4 | 364.2 |
| 335 | 61.85 | 143 | 1.054 | 1.008 | 1.400 1 | 20.08 | 28.90 | .700 | 335.5 | 366.9 |
| 340 | 66.85 | 152 | 1.038 | 1.008 | 1.399 9 | 20.30 | 29.28 | .699 | 340.5 | 369.6 |
| 345 | 71.85 | 161 | 1.023 | 1.009 | 1.399 6 | 20.52 | 29.64 | .698 | 345.6 | 372.3 |
| 350 | 76.85 | 170 | 1.008 | 1.009 | 1.399 3 | 20.75 | 30.03 | .697 | 350.6 | 375.0 |
| 355 | 81.85 | 179 | 0.994 5 | 1.010 | 1.399 0 | 20.97 | 30.39 | .696 | 355.7 | 377.6 |
| 360 | 86.85 | 188 | 0.980 5 | 1.010 | 1.398 7 | 21.18 | 30.78 | .695 | 360.7 | 380.2 |
| 365 | 91.85 | 197 | 0.967 2 | 1.010 | 1.398 4 | 21.38 | 31.14 | .694 | 365.8 | 382.8 |
| 370 | 96.85 | 206 | 0.953 9 | 1.011 | 1.398 1 | 21.60 | 31.50 | .693 | 370.8 | 385.4 |
| 375 | 101.85 | 215 | 0.941 3 | 1.011 | 1.397 8 | 21.81 | 31.86 | .692 | 375.9 | 388.0 |
| 380 | 106.85 | 224 | 0.928 8 | 1.012 | 1.397 5 | 22.02 | 32.23 | .691 | 380.9 | 390.5 |
| 385 | 111.85 | 233 | 0.916 9 | 1.012 | 1.397 1 | 22.24 | 32.59 | .690 | 386.0 | 393.0 |
| 390 | 116.85 | 242 | 0.905 0 | 1.013 | 1.396 8 | 22.44 | 32.95 | .690 | 391.0 | 395.5 |
| 395 | 121.85 | 251 | 0.893 6 | 1.014 | 1.396 4 | 22.65 | 33.31 | .689 | 396.1 | 398.0 |
| 400 | 126.85 | 260 | 0.882 2 | 1.014 | 1.396 1 | 22.86 | 33.65 | .689 | 401.2 | 400.4 |
| 410 | 136.85 | 278 | 0.860 8 | 1.015 | 1.395 3 | 23.27 | 34.35 | .688 | 411.3 | 405.3 |
| 420 | 146.85 | 296 | 0.840 2 | 1.017 | 1.394 6 | 23.66 | 35.05 | .687 | 421.5 | 410.2 |
| 430 | 156.85 | 314 | 0.820 7 | 1.018 | 1.393 8 | 24.06 | 35.75 | .686 | 431.7 | 414.9 |
| 440 | 166.85 | 332 | 0.802 1 | 1.020 | 1.392 9 | 24.45 | 36.43 | .684 | 441.9 | 419.6 |
| 450 | 176.85 | 350 | 0.784 2 | 1.021 | 1.392 0 | 24.85 | 37.10 | .684 | 452.1 | 424.2 |
| 460 | 186.85 | 368 | 0.767 7 | 1.023 | 1.391 1 | 25.22 | 37.78 | .683 | 462.3 | 428.7 |
| 470 | 196.85 | 386 | 0.750 9 | 1.024 | 1.390 1 | 25.58 | 38.46 | .682 | 472.5 | 433.2 |
| 480 | 206.85 | 404 | 0.735 1 | 1.026 | 1.389 2 | 25.96 | 39.11 | .681 | 482.8 | 437.6 |
| 490 | 216.85 | 422 | 0.720 1 | 1.028 | 1.388 1 | 26.32 | 39.76 | .680 | 493.0 | 442.0 |
| 500 | 226.85 | 440 | 0.705 7 | 1.030 | 1.387 1 | 26.70 | 40.41 | .680 | 503.3 | 446.4 |
| 510 | 236.85 | 458 | 0.691 9 | 1.032 | 1.386 1 | 27.06 | 41.06 | .680 | 513.6 | 450.6 |
| 520 | 246.85 | 476 | 0.678 6 | 1.034 | 1.385 1 | 27.42 | 41.69 | .680 | 524.0 | 454.9 |
| 530 | 256.85 | 494 | 0.665 8 | 1.036 | 1.384 0 | 27.78 | 42.32 | .680 | 534.3 | 459.0 |
| 540 | 266.85 | 512 | 0.653 5 | 1.038 | 1.382 9 | 28.14 | 42.94 | .680 | 544.7 | 463.2 |
| 550 | 276.85 | 530 | 0.641 6 | 1.040 | 1.381 8 | 28.48 | 43.57 | .680 | 555.1 | 467.3 |
| 560 | 286.85 | 548 | 0.630 1 | 1.042 | 1.380 6 | 28.83 | 44.20 | .680 | 565.5 | 471.3 |
| 570 | 296.85 | 566 | 0.619 0 | 1.044 | 1.379 5 | 29.17 | 44.80 | .680 | 575.9 | 475.3 |
| 580 | 306.85 | 584 | 0.608 4 | 1.047 | 1.378 3 | 29.52 | 45.41 | .680 | 586.4 | 479.2 |
| 590 | 316.85 | 602 | 0.598 0 | 1.049 | 1.377 2 | 29.84 | 46.01 | .680 | 596.9 | 483.2 |
| 600 | 326.85 | 620 | 0.588 1 | 1.051 | 1.376 0 | 30.17 | 46.61 | .680 | 607.4 | 486.9 |
| 620 | 346.85 | 656 | 0.569 1 | 1.056 | 1.373 7 | 30.82 | 47.80 | .681 | 628.4 | 494.5 |
| 640 | 366.85 | 692 | 0.551 4 | 1.061 | 1.371 4 | 31.47 | 48.96 | .682 | 649.6 | 502.1 |
| 660 | 386.85 | 728 | 0.534 7 | 1.065 | 1.369 1 | 32.09 | 50.12 | .682 | 670.9 | 509.4 |
| 680 | 406.85 | 764 | 0.518 9 | 1.070 | 1.366 8 | 32.71 | 51.25 | .683 | 692.2 | 516.7 |
| 700 | 426.85 | 800 | 0.504 0 | 1.075 | 1.364 6 | 33.32 | 52.36 | .684 | 713.7 | 523.7 |
| 720 | 446.85 | 836 | 0.490 1 | 1.080 | 1.362 3 | 33.92 | 53.45 | .685 | 735.2 | 531.0 |
| 740 | 466.85 | 872 | 0.476 9 | 1.085 | 1.360 1 | 34.52 | 54.53 | .686 | 756.9 | 537.6 |
| 760 | 486.85 | 908 | 0.464 3 | 1.089 | 1.358 0 | 35.11 | 55.62 | .687 | 778.6 | 544.6 |
| 780 | 506.85 | 944 | 0.452 4 | 1.094 | 1.355 9 | 35.69 | 56.68 | .688 | 800.5 | 551.2 |
| 800 | 526.85 | 980 | 0.441 0 | 1.099 | 1.354 | 36.24 | 57.74 | .689 | 822.4 | 557.8 |
| 850 | 576.85 | 1 070 | 0.415 2 | 1.110 | 1.349 | 37.63 | 60.30 | .693 | 877.5 | 574.1 |
| 900 | 626.85 | 1 160 | 0.392 0 | 1.121 | 1.345 | 38.97 | 62.76 | .696 | 933.4 | 589.6 |
| 950 | 676.85 | 1 250 | 0.371 4 | 1.132 | 1.340 | 40.26 | 65.20 | .699 | 989.7 | 604.9 |
| 1 000 | 726.85 | 1 340 | 0.352 9 | 1.142 | 1.336 | 41.53 | 67.54 | .702 | 1 046 | 619.5 |
| 1 100 | 826.85 | 1 520 | 0.320 8 | 1.161 | 1.329 | 43.96 | | | 1 162 | 648.0 |
| 1 200 | 926.85 | 1 700 | 0.294 1 | 1.179 | 1.322 | 46.26 | | | 1 279 | 675.2 |
| 1 300 | 1 026.85 | 1 880 | 0.271 4 | 1.197 | 1.316 | 48.46 | | | 1 398 | 701.0 |
| 1 400 | 1 126.85 | 2 060 | 0.252 1 | 1.214 | 1.310 | 50.57 | | | 1 518 | 725.9 |
| 1 500 | 1 220.85 | 2 240 | 0.235 3 | 1.231 | 1.304 | 52.61 | | | 1 640 | 749.4 |
| 1 600 | 1 326.85 | 2 420 | 0.220 6 | 1.249 | 1.299 | 54.57 | | | 1 764 | 772.6 |
| 1 800 | 1 526.85 | 2 780 | 0.196 0 | 1.288 | 1.288 | 58.29 | | | 2 018 | 815.7 |
| 2 000 | 1 726.85 | 3 140 | 0.176 4 | 1.338 | 1.274 | | | | 2 280 | 855.5 |
| 2 400 | 2 126.85 | 3 860 | 0.146 7 | 1.574 | 1.238 | | | | 2 853 | 924.4 |
| 2 800 | 2 526.85 | 4 580 | 0.124 5 | 2.259 | 1.196 | | | | 3 599 | 983.1 |

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**TABLE A.2 Ideal Gas Properties of Nitrogen, Oxygen, and Carbon Dioxide**

## Symbols and Units:

$T$ = absolute temperature, degrees Kelvin
$\bar{h}$ = enthalpy, kJ/kmol
$\bar{u}$ = internal energy, kJ/kmol
$\bar{s}°$ = absolute entropy at standard reference pressure, kJ/kmol K
[$\bar{h}$ = enthalpy of formation per mole at standard state = 0 kJ/kmol]

### Part a. Ideal Gas Properties of Nitrogen, $N_2$

| $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}°$ | $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}°$ |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 600 | 17,563 | 12,574 | 212.066 |
| 220 | 6,391 | 4,562 | 182.639 | 610 | 17,864 | 12,792 | 212.564 |
| 230 | 6,683 | 4,770 | 183.938 | 620 | 18,166 | 13,011 | 213.055 |
| 240 | 6,975 | 4,979 | 185.180 | 630 | 18,468 | 13,230 | 213.541 |
| 250 | 7,266 | 5,188 | 186.370 | 640 | 18,772 | 13,450 | 214.018 |
| 260 | 7,558 | 5,396 | 187.514 | 650 | 19,075 | 13,671 | 214.489 |
| 270 | 7,849 | 5,604 | 188.614 | 660 | 19,380 | 13,892 | 214.954 |
| 280 | 8,141 | 5,813 | 189.673 | 670 | 19,685 | 14,114 | 215.413 |
| 290 | 8,432 | 6,021 | 190.695 | 680 | 19,991 | 14,337 | 215.866 |
| 298 | 8,669 | 6,190 | 191.502 | 690 | 20,297 | 14,560 | 216.314 |
| 300 | 8,723 | 6,229 | 191.682 | 700 | 20,604 | 14,784 | 216.756 |
| 310 | 9,014 | 6,437 | 192.638 | 710 | 20,912 | 15,008 | 217.192 |
| 320 | 9,306 | 6,645 | 193.562 | 720 | 21,220 | 15,234 | 217.624 |
| 330 | 9,597 | 6,853 | 194.459 | 730 | 21,529 | 15,460 | 218.059 |
| 340 | 9,888 | 7,061 | 195.328 | 740 | 21,839 | 15,686 | 218.472 |
| 350 | 10,180 | 7,270 | 196.173 | 750 | 22,149 | 15,913 | 218.889 |
| 360 | 10,471 | 7,478 | 196.995 | 760 | 22,460 | 16,141 | 219.301 |
| 370 | 10,763 | 7,687 | 197.794 | 770 | 22,772 | 16,370 | 219.709 |
| 380 | 11,055 | 7,895 | 198.572 | 780 | 23,085 | 16,599 | 220.113 |
| 390 | 11,347 | 8,104 | 199.331 | 790 | 23,398 | 16,830 | 220.512 |
| 400 | 11,640 | 8,314 | 200.071 | 800 | 23,714 | 17,061 | 220.907 |
| 410 | 11,932 | 8,523 | 200.794 | 810 | 24,027 | 17,292 | 221.298 |
| 420 | 12,225 | 8,733 | 201.499 | 820 | 24,342 | 17,524 | 221.684 |
| 430 | 12,518 | 8,943 | 202.189 | 830 | 24,658 | 17,757 | 222.067 |
| 440 | 12,811 | 9,153 | 202.863 | 840 | 24,974 | 17,990 | 222.447 |
| 450 | 13,105 | 9,363 | 203.523 | 850 | 25,292 | 18,224 | 222.822 |
| 460 | 13,399 | 9,574 | 204.170 | 860 | 25,610 | 18,459 | 223.194 |
| 470 | 13,693 | 9,786 | 204.803 | 870 | 25,928 | 18,695 | 223.562 |
| 480 | 13,988 | 9,997 | 205.424 | 880 | 26,248 | 18,931 | 223.927 |
| 490 | 14,285 | 10,210 | 206.033 | 890 | 26,568 | 19,168 | 224.288 |
| 500 | 14,581 | 10,423 | 206.630 | 900 | 26,890 | 19,407 | 224.647 |
| 510 | 14,876 | 10,635 | 207.216 | 910 | 27,210 | 19,644 | 225.002 |
| 520 | 15,172 | 10,848 | 207.792 | 920 | 27,532 | 19,883 | 225.353 |
| 530 | 15,469 | 11,062 | 208.358 | 930 | 27,854 | 20,122 | 225.701 |
| 540 | 15,766 | 11,277 | 208.914 | 940 | 28,178 | 20,362 | 226.047 |
| 550 | 16,064 | 11,492 | 209.461 | 950 | 28,501 | 20,603 | 226.389 |
| 560 | 16,363 | 11,707 | 209.999 | 960 | 28,826 | 20,844 | 226.728 |
| 570 | 16,662 | 11,923 | 210.528 | 970 | 29,151 | 21,086 | 227.064 |
| 580 | 16,962 | 12,139 | 211.049 | 980 | 29,476 | 21,328 | 227.398 |
| 590 | 17,26_ | 12,356 | 211.562 | 990 | 29,803 | 21,571 | 227.728 |

*Source:* Adapted from M.J. Moran and H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, 3rd. ed., Wiley, New York, 1995, as presented in K. Wark. *Thermodynamics*, 4th ed., McGraw-Hill, New York, 1983, based on the *JANAF Thermochemical Tables*, NSRDS-NBS-37, 1971.

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**TABLE A.2 (continued) Ideal Gas Properties of Nitrogen, Oxygen, and Carbon Dioxide**

| $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ | $T$ | $n$ | $\bar{u}$ | $\bar{s}^\circ$ |
|---|---|---|---|---|---|---|---|
| 1000 | 30,129 | 21,815 | 228.057 | 1760 | 56,227 | 41.594 | 247.396 |
| 1020 | 30,784 | 22,304 | 228.706 | 1780 | 56,938 | 42,139 | 247.798 |
| 1040 | 31,442 | 22,795 | 229.344 | 1800 | 57,651 | 42,685 | 248.195 |
| 1060 | 32,101 | 23,288 | 229.973 | 1820 | 58,363 | 43,231 | 248.589 |
| 1080 | 32,762 | 23,782 | 230.591 | 1840 | 59,075 | 43,777 | 248.979 |
| 1100 | 33,426 | 24,280 | 231.199 | 1860 | 59,790 | 44,324 | 249.365 |
| 1120 | 34,092 | 24,780 | 231.799 | 1880 | 60,504 | 44,873 | 249.748 |
| 1140 | 34,760 | 25,282 | 232.391 | 1900 | 61,220 | 45,423 | 250.128 |
| 1160 | 35,430 | 25,786 | 232.973 | 1920 | 61,936 | 45,973 | 250.502 |
| 1180 | 36,104 | 26,291 | 233.549 | 1940 | 62,654 | 46,524 | 250.874 |
| 1200 | 36,777 | 26,799 | 234.115 | 1960 | 63,381 | 47,075 | 251.242 |
| 1220 | 37,452 | 27,308 | 234.673 | 1980 | 64,090 | 47,627 | 251.607 |
| 1240 | 38,129 | 27,819 | 235.223 | 2000 | 64,810 | 48,181 | 251.969 |
| 1260 | 38,807 | 28,331 | 235.766 | 2050 | 66,612 | 49,567 | 252.858 |
| 1280 | 39,488 | 28,845 | 236.302 | 2100 | 68,417 | 50,957 | 253.726 |
| 1300 | 40,170 | 29,361 | 236.831 | 2150 | 70,226 | 52,351 | 254.578 |
| 1320 | 40,853 | 29,878 | 237.353 | 2200 | 72,040 | 53,749 | 255.412 |
| 1340 | 41,539 | 30,398 | 237.867 | 2250 | 73,856 | 55,149 | 256.227 |
| 1360 | 42,227 | 30,919 | 238.376 | 2300 | 75,676 | 56,553 | 257.027 |
| 1380 | 42,915 | 31,441 | 238.878 | 2350 | 77,496 | 57,958 | 257.810 |
| 1400 | 43,605 | 31,964 | 239.375 | 2400 | 79,320 | 59,366 | 258.580 |
| 1420 | 44,295 | 32,489 | 239.865 | 2450 | 81,149 | 60,779 | 259.332 |
| 1440 | 44,988 | 33,014 | 240.350 | 2500 | 82,981 | 62,195 | 260.073 |
| 1460 | 45,682 | 33,543 | 240.827 | 2550 | 84,814 | 63,613 | 260.799 |
| 1480 | 46,377 | 34,071 | 241.301 | 2600 | 86,650 | 65,033 | 261.512 |
| 1500 | 47,073 | 34,601 | 241.768 | 2650 | 88,488 | 66,455 | 262.213 |
| 1520 | 47,771 | 35,133 | 242.228 | 2700 | 90,328 | 67,880 | 262.902 |
| 1540 | 48,470 | 35,665 | 242.685 | 2750 | 92,171 | 69,306 | 263.577 |
| 1560 | 49,168 | 36,197 | 243.137 | 2800 | 94,014 | 70,734 | 264.241 |
| 1580 | 49,869 | 36,732 | 243.585 | 2850 | 95,859 | 72,163 | 264.895 |
| 1600 | 50,571 | 37,268 | 244.028 | 2900 | 97,705 | 73,593 | 265.538 |
| 1620 | 51,275 | 37,806 | 244.464 | 2950 | 99,556 | 75,028 | 266.170 |
| 1640 | 51,980 | 38,344 | 244.896 | 3000 | 101,407 | 76,464 | 266.793 |
| 1660 | 52,686 | 38,884 | 245.324 | 3050 | 103,260 | 77,902 | 267.404 |
| 1680 | 53,393 | 39,424 | 245.747 | 3100 | 105,115 | 79,341 | 268.007 |
| 1700 | 54,099 | 39,965 | 246.166 | 3150 | 106,972 | 80,782 | 268.601 |
| 1720 | 54,807 | 40,507 | 246.580 | 3200 | 108,830 | 82,224 | 269.186 |
| 1740 | 55,516 | 41,049 | 246.990 | 3250 | 110,690 | 83,668 | 269.763 |

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**TABLE A.2 (continued) Ideal Gas Properties of Nitrogen, Oxygen, and Carbon Dioxide**

**Part b. Ideal Gas Properties of Oxygen, $O_2$**

| $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ | $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 600 | 17,929 | 12,940 | 226.346 |
| 220 | 6,404 | 4,575 | 196.171 | 610 | 18,250 | 13,178 | 226.877 |
| 230 | 6,694 | 4,782 | 197.461 | 620 | 18,572 | 13,417 | 227.400 |
| 240 | 6,984 | 4,989 | 198.696 | 630 | 18,895 | 13,657 | 227.918 |
| 250 | 7,275 | 5,197 | 199.885 | 640 | 19,219 | 13,898 | 228.429 |
| 260 | 7,566 | 5,405 | 201.027 | 650 | 19,544 | 14,140 | 228.932 |
| 270 | 7,858 | 5,613 | 202.128 | 660 | 19,870 | 14,383 | 229.430 |
| 280 | 8,150 | 5,822 | 203.191 | 670 | 20,197 | 14,626 | 229.920 |
| 290 | 8,443 | 6,032 | 204.218 | 680 | 20,524 | 14,871 | 230.405 |
| 298 | 8,682 | 6,203 | 205.033 | 690 | 20,854 | 15,116 | 230.885 |
| 300 | 8,736 | 6,242 | 205.213 | 700 | 21,184 | 15,364 | 231.358 |
| 310 | 9,030 | 6,453 | 206.177 | 710 | 21,514 | 15,611 | 231.827 |
| 320 | 9,325 | 6,664 | 207.112 | 720 | 21,845 | 15,859 | 232.291 |
| 330 | 9,620 | 6,877 | 208.020 | 730 | 22,177 | 16,107 | 232.748 |
| 340 | 9,916 | 7,090 | 208.904 | 740 | 22,510 | 16,357 | 233.201 |
| 350 | 10,213 | 7,303 | 209.765 | 750 | 22,844 | 16,607 | 233.649 |
| 360 | 10,511 | 7,518 | 210.604 | 760 | 23,178 | 16,859 | 234.091 |
| 370 | 10,809 | 7,733 | 211.423 | 770 | 23,513 | 17,111 | 234.528 |
| 380 | 11,109 | 7,949 | 212.222 | 780 | 23,850 | 17,364 | 234.960 |
| 390 | 11,409 | 8,166 | 213.002 | 790 | 24,186 | 17,618 | 235.387 |
| 400 | 11,711 | 8,384 | 213.765 | 800 | 24,523 | 17,872 | 235.810 |
| 410 | 12,012 | 8,603 | 214.510 | 810 | 24,861 | 18,126 | 236.230 |
| 420 | 12,314 | 8,822 | 215.241 | 820 | 25,199 | 18,382 | 236.644 |
| 430 | 12,618 | 9,043 | 215.955 | 830 | 25,537 | 18,637 | 237.055 |
| 440 | 12,923 | 9,264 | 216.656 | 840 | 25,877 | 18,893 | 237.462 |
| 450 | 13,228 | 9,487 | 217.342 | 850 | 26,218 | 19,150 | 237.864 |
| 460 | 13,535 | 9,710 | 218.016 | 860 | 26,559 | 19,408 | 238.264 |
| 470 | 13,842 | 9,935 | 218.676 | 870 | 26,899 | 19,666 | 238.660 |
| 480 | 14,151 | 10,160 | 219.326 | 880 | 27,242 | 19,925 | 239.051 |
| 490 | 14,460 | 10,386 | 219.963 | 890 | 27,584 | 20,185 | 239.439 |
| 500 | 14,770 | 10,614 | 220.589 | 900 | 27,928 | 20,445 | 239.823 |
| 510 | 15,082 | 10,842 | 221.206 | 910 | 28,272 | 20,706 | 240.203 |
| 520 | 15,395 | 11,071 | 221.812 | 920 | 28,616 | 20,967 | 240.580 |
| 530 | 15,708 | 11,301 | 222.409 | 930 | 28,960 | 21,228 | 240.953 |
| 540 | 16,022 | 11,533 | 222.997 | 940 | 29,306 | 21,491 | 241.323 |
| 550 | 16,338 | 11,765 | 223.576 | 950 | 29,652 | 21,754 | 241.689 |
| 560 | 16,654 | 11,998 | 224.146 | 960 | 29,999 | 22,017 | 242.052 |
| 570 | 16,971 | 12,232 | 224.708 | 970 | 30,345 | 22,280 | 242.411 |
| 580 | 17,290 | 12,467 | 225.262 | 980 | 30,692 | 22,544 | 242.768 |
| 590 | 17,609 | 12,703 | 225.808 | 990 | 31,041 | 22,809 | 243.120 |

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**TABLE A.2 (continued) Ideal Gas Properties of Nitrogen, Oxygen, and Carbon Dioxide**

| $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}°$ | $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}°$ |
|---|---|---|---|---|---|---|---|
| 1000 | 31,389 | 23,075 | 243.471 | 1760 | 58,880 | 44,247 | 263.861 |
| 1020 | 32,088 | 23,607 | 244.164 | 1780 | 59,624 | 44,825 | 264.283 |
| 1040 | 32,789 | 24,142 | 244.844 | 1800 | 60,371 | 45,405 | 264.701 |
| 1060 | 33,490 | 24,677 | 245.513 | 1820 | 61,118 | 45,986 | 265.113 |
| 1080 | 34,194 | 25,214 | 246.171 | 1840 | 61,866 | 46,568 | 265.521 |
| 1100 | 34,899 | 25,753 | 246.818 | 1860 | 62,616 | 47,151 | 265.925 |
| 1120 | 35,606 | 26,294 | 247.454 | 1880 | 63,365 | 47,734 | 266.326 |
| 1140 | 36,314 | 26,836 | 248.081 | 1900 | 64,116 | 48,319 | 266.722 |
| 1160 | 37,023 | 27,379 | 248.698 | 1920 | 64,868 | 48,904 | 267.115 |
| 1180 | 37,734 | 27,923 | 249.307 | 1940 | 65,620 | 49,490 | 267.505 |
| 1200 | 38,447 | 28,469 | 249.906 | 1960 | 66,374 | 50,078 | 267.891 |
| 1220 | 39,162 | 29,018 | 250.497 | 1980 | 67,127 | 50,665 | 268.275 |
| 1240 | 39,877 | 29,568 | 251.079 | 2000 | 67,881 | 51,253 | 268.655 |
| 1260 | 40,594 | 30,118 | 251.653 | 2050 | 69,772 | 52,727 | 269.588 |
| 1280 | 41,312 | 30,670 | 252.219 | 2100 | 71,668 | 54,208 | 270.504 |
| 1300 | 42,033 | 31,224 | 252.776 | 2150 | 73,573 | 55,697 | 271.399 |
| 1320 | 42,753 | 31,778 | 253.325 | 2200 | 75,484 | 57,192 | 272.278 |
| 1340 | 43,475 | 32,334 | 253.868 | 2250 | 77,397 | 58,690 | 273.136 |
| 1360 | 44,198 | 32,891 | 254.404 | 2300 | 79,316 | 60,193 | 273.981 |
| 1380 | 44,923 | 33,449 | 254.932 | 2350 | 81,243 | 61,704 | 274.809 |
| 1400 | 45,648 | 34,008 | 255.454 | 2400 | 83,174 | 63,219 | 275.625 |
| 1420 | 46,374 | 34,567 | 255.968 | 2450 | 85,112 | 64,742 | 276.424 |
| 1440 | 47,102 | 35,129 | 256.475 | 2500 | 87,057 | 66,271 | 277.207 |
| 1460 | 47,831 | 35,692 | 256.978 | 2550 | 89,004 | 67,802 | 277.979 |
| 1480 | 48,561 | 36,256 | 257.474 | 2600 | 90,956 | 69,339 | 278.738 |
| 1500 | 49,292 | 36,821 | 257.965 | 2650 | 92,916 | 70,883 | 279.485 |
| 1520 | 50,024 | 37,387 | 258.450 | 2700 | 94,881 | 72,433 | 280.219 |
| 1540 | 50,756 | 37,952 | 258.928 | 2750 | 96,852 | 73,987 | 280.942 |
| 1560 | 51,490 | 38,520 | 259.402 | 2800 | 98,826 | 75,546 | 281.654 |
| 1580 | 52,224 | 39,088 | 259.870 | 2850 | 100,808 | 77,112 | 282.357 |
| 1600 | 52,961 | 39,658 | 260.333 | 2900 | 102,793 | 78,682 | 283.048 |
| 1620 | 53,696 | 40,227 | 260.791 | 2950 | 104,785 | 80,258 | 283.728 |
| 1640 | 54,434 | 40,799 | 261.242 | 3000 | 106,780 | 81,837 | 284.399 |
| 1660 | 55,172 | 41,370 | 261.690 | 3050 | 108,778 | 83,419 | 285.060 |
| 1680 | 55,912 | 41,944 | 262.132 | 3100 | 110,784 | 85,009 | 285.713 |
| 1700 | 56,652 | 42,517 | 262.571 | 3150 | 112,795 | 86,601 | 286.355 |
| 1720 | 57,394 | 43,093 | 263.005 | 3200 | 114,809 | 88,203 | 286.989 |
| 1740 | 58,136 | 43,669 | 263.435 | 3250 | 116,827 | 89,804 | 287.614 |

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**TABLE A.2 (continued) Ideal Gas Properties of Nitrogen, Oxygen, and Carbon Dioxide**

**Part c. Ideal Gas Properties of Carbon Dioxide, $CO_2$**

| $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ | $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 600 | 22,280 | 17,291 | 243.199 |
| 220 | 6,601 | 4,772 | 202.966 | 610 | 22,754 | 17,683 | 243.983 |
| 230 | 6,938 | 5,026 | 204.464 | 620 | 23,231 | 18,076 | 244.758 |
| 240 | 7,280 | 5,285 | 205.920 | 630 | 23,709 | 18,471 | 245.524 |
| 250 | 7,627 | 5,548 | 207.337 | 640 | 24,190 | 18,869 | 246.282 |
| 260 | 7,979 | 5,817 | 208.717 | 650 | 24,674 | 19,270 | 247.032 |
| 270 | 8,335 | 6,091 | 210.062 | 660 | 25,160 | 19,672 | 247.773 |
| 280 | 8,697 | 6,369 | 211.376 | 670 | 25,648 | 20,078 | 248.507 |
| 290 | 9,063 | 6,651 | 212.660 | 680 | 26,138 | 20,484 | 249.233 |
| 298 | 9,364 | 6,885 | 213.685 | 690 | 26,631 | 20,894 | 249.952 |
| 300 | 9,431 | 6,939 | 213.915 | 700 | 27,125 | 21,305 | 250.663 |
| 310 | 9,807 | 7,230 | 215.146 | 710 | 27,622 | 21,719 | 251.368 |
| 320 | 10,186 | 7,526 | 216.351 | 720 | 28,121 | 22,134 | 252.065 |
| 330 | 10,570 | 7,826 | 217.534 | 730 | 28,622 | 22,552 | 252.755 |
| 340 | 10,959 | 8,131 | 218.694 | 740 | 29,124 | 22,972 | 253.439 |
| 350 | 11,351 | 8,439 | 219.831 | 750 | 29,629 | 23,393 | 254.117 |
| 360 | 11,748 | 8,752 | 220.948 | 760 | 30,135 | 23,817 | 254.787 |
| 370 | 12,148 | 9,068 | 222.044 | 770 | 30,644 | 24,242 | 255.452 |
| 380 | 12,552 | 9,392 | 223.122 | 780 | 31,154 | 24,669 | 256.110 |
| 390 | 12,960 | 9,718 | 224.182 | 790 | 31,665 | 25,097 | 256.762 |
| 400 | 13,372 | 10,046 | 225.225 | 800 | 32,179 | 25,527 | 257.408 |
| 410 | 13,787 | 10,378 | 226.250 | 810 | 32,694 | 25,959 | 258.048 |
| 420 | 14,206 | 10,714 | 227.258 | 820 | 33,212 | 26,394 | 258.682 |
| 430 | 14,628 | 11,053 | 228.252 | 830 | 33,730 | 26,829 | 259.311 |
| 440 | 15,054 | 11,393 | 229.230 | 840 | 34,251 | 27,267 | 259.934 |
| 450 | 15,483 | 11,742 | 230.194 | 850 | 34,773 | 27,706 | 260.551 |
| 460 | 15,916 | 12,091 | 231.144 | 860 | 35,296 | 28,125 | 261.164 |
| 470 | 16,351 | 12,444 | 232.080 | 870 | 35,821 | 28,588 | 261.770 |
| 480 | 16,791 | 12,800 | 233.004 | 880 | 36,347 | 29,031 | 262.371 |
| 490 | 17,232 | 13,158 | 233.916 | 890 | 36,876 | 29,476 | 262.968 |
| 500 | 17,678 | 13,521 | 234.814 | 900 | 37,405 | 29,922 | 263.559 |
| 510 | 18,126 | 13,885 | 235.700 | 910 | 37,935 | 30,369 | 264.146 |
| 520 | 18,576 | 14,253 | 236.575 | 920 | 38,467 | 30,818 | 264.728 |
| 530 | 19,029 | 14,622 | 237.439 | 930 | 39,000 | 31,268 | 265.304 |
| 540 | 19,485 | 14,996 | 238.292 | 940 | 39,535 | 31,719 | 265.877 |
| 550 | 19,945 | 15,372 | 239.135 | 950 | 40,070 | 32,171 | 266.444 |
| 560 | 20,407 | 15,751 | 239.962 | 960 | 40,607 | 32,625 | 267.007 |
| 570 | 20,870 | 16,131 | 240.789 | 970 | 41,145 | 33,081 | 267.566 |
| 580 | 21,337 | 16,515 | 241.602 | 980 | 41,685 | 33,537 | 268.119 |
| 590 | 21,807 | 16,902 | 242.405 | 990 | 42,226 | 33,995 | 268.670 |

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**TABLE A.2 (continued) Ideal Gas Properties of Nitrogen, Oxygen, and Carbon Dioxide**

| $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ | $T$ | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ |
|---|---|---|---|---|---|---|---|
| 1000 | 42,769 | 34,455 | 269.215 | 1760 | 86,420 | 71,787 | 301.543 |
| 1020 | 43,859 | 35,378 | 270.293 | 1780 | 87,612 | 72,812 | 302.271 |
| 1040 | 44,953 | 36,306 | 271.354 | 1800 | 88,806 | 73,840 | 302.884 |
| 1060 | 46,051 | 37,238 | 272.400 | 1820 | 90,000 | 74,868 | 303.544 |
| 1080 | 47,153 | 38,174 | 273.430 | 1840 | 91,196 | 75,897 | 304.198 |
| 1100 | 48,258 | 39,112 | 274.445 | 1860 | 92,394 | 76,929 | 304.845 |
| 1120 | 49,369 | 40,057 | 275.444 | 1880 | 93,593 | 77,962 | 305.487 |
| 1140 | 50,484 | 41,006 | 276.430 | 1900 | 94,793 | 78,996 | 306.122 |
| 1160 | 51,602 | 41,957 | 277.403 | 1920 | 95,995 | 80,031 | 306.751 |
| 1180 | 52,724 | 42,913 | 278.362 | 1940 | 97,197 | 81,067 | 307.374 |
| 1200 | 53,848 | 43,871 | 279.307 | 1960 | 98,401 | 82,105 | 307.992 |
| 1220 | 54,977 | 44,834 | 280.238 | 1980 | 99,606 | 83,144 | 308.604 |
| 1240 | 56,108 | 45,799 | 281.158 | 2000 | 100,804 | 84,185 | 309.210 |
| 1260 | 57,244 | 46,768 | 282.066 | 2050 | 103,835 | 86,791 | 310.701 |
| 1280 | 58,381 | 47,739 | 282.962 | 2100 | 106,864 | 89,404 | 312.160 |
| 1300 | 59,522 | 48,713 | 283.847 | 2150 | 109,898 | 92,023 | 313.589 |
| 1320 | 60,666 | 49,691 | 284.722 | 2200 | 112,939 | 94,648 | 314.988 |
| 1340 | 61,813 | 50,672 | 285.586 | 2250 | 115,984 | 97,277 | 316.356 |
| 1360 | 62,963 | 51,656 | 286.439 | 2300 | 119,035 | 99,912 | 317.695 |
| 1380 | 64,116 | 52,643 | 287.283 | 2350 | 122,091 | 102,552 | 319.011 |
| 1400 | 65,271 | 53,631 | 288.106 | 2400 | 125,152 | 105,197 | 320.302 |
| 1420 | 66,427 | 54,621 | 288.934 | 2450 | 128,219 | 107,849 | 321.566 |
| 1440 | 67,586 | 55,614 | 289.743 | 2500 | 131,290 | 110,504 | 322.808 |
| 1460 | 68,748 | 56,609 | 290.542 | 2550 | 134,368 | 113,166 | 324.026 |
| 1480 | 69,911 | 57,606 | 291.333 | 2600 | 137,449 | 115,832 | 325.222 |
| 1500 | 71,078 | 58,606 | 292.114 | 2650 | 140,533 | 118,500 | 326.396 |
| 1520 | 72,246 | 59,609 | 292.888 | 2700 | 143,620 | 121,172 | 327.549 |
| 1540 | 73,417 | 60,613 | 292.654 | 2750 | 146,713 | 123,849 | 328.684 |
| 1560 | 74,590 | 61,620 | 294.411 | 2800 | 149,808 | 126,528 | 329.800 |
| 1580 | 76,767 | 62,630 | 295.161 | 2850 | 152,908 | 129,212 | 330.896 |
| 1600 | 76,944 | 63,741 | 295.901 | 2900 | 156,009 | 131,898 | 331.975 |
| 1620 | 78,123 | 64,653 | 296.632 | 2950 | 159,117 | 134,589 | 333.037 |
| 1640 | 79,303 | 65,668 | 297.356 | 3000 | 162,226 | 137,283 | 334.084 |
| 1660 | 80,486 | 66,592 | 298.072 | 3050 | 165,341 | 139,982 | 335.114 |
| 1680 | 81,670 | 67,702 | 298.781 | 3100 | 168,456 | 142,681 | 336.126 |
| 1700 | 82,856 | 68,721 | 299.482 | 3150 | 171,576 | 145,385 | 337.124 |
| 1720 | 84,043 | 69,742 | 300.177 | 3200 | 174,695 | 148,089 | 338.109 |
| 1740 | 85,231 | 70,764 | 300.863 | 3250 | 177,822 | 150,801 | 339.069 |

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**TABLE A.3 Psychrometric Table: Properties of Moist Air at 101 325 N/m²**

## Symbols and Units:

$P_s$ = pressure of water vapor at saturation, N/m²
$W_s$ = humidity ratio at saturation, mass of water vapor associated with unit mass of dry air
$V_a$ = specific volume of dry air, m³/kg
$V_s$ = specific volume of saturated mixture, m³/kg dry air
$h_a^a$ = specific enthalpy of dry air, kJ/kg
$h_s$ = specific enthalpy of saturated mixture, kJ/kg dry air
$s_s$ = specific entropy of saturated mixture, J/K·kg dry air

| *Temperature* | | | *Properties* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *C* | *K* | *F* | $P_s$ | $W_s$ | $V_a$ | $V_s$ | $h_a$ | $h_s$ | $s_s$ |
| −40 | 233.15 | −40 | 12.838 | 0.000 079 25 | 0.659 61 | 0.659 68 | −22.35 | −22.16 | −90.659 |
| −30 | 243.15 | −22 | 37.992 | 0.000 234 4 | 0.688 08 | 0.688 33 | −12.29 | −11.72 | −46.732 |
| −25 | 248.15 | −13 | 63.248 | 0.000 390 3 | 0.702 32 | 0.702 75 | −7.265 | −6.306 | −24.706 |
| −20 | 253.15 | −4 | 103.19 | 0.000 637 1 | 0.716 49 | 0.717 24 | −2.236 | −0.6653 | −2.2194 |
| −15 | 258.15 | +5 | 165.18 | 0.001 020 | 0.730 72 | 0.731 91 | +2.794 | 5.318 | 21.189 |
| −10 | 263.15 | 14 | 259.72 | 0.001 606 | 0.744 95 | 0.746 83 | 7.823 | 11.81 | 46.104 |
| −5 | 268.15 | 23 | 401.49 | 0.002 485 | 0.759 12 | 0.762 18 | 12.85 | 19.04 | 73.365 |
| 0 | 273.15 | 32 | 610.80 | 0.003 788 | 0.773 36 | 0.778 04 | 17.88 | 27.35 | 104.14 |
| 5 | 278.15 | 41 | 871.93 | 0.005 421 | 0.787 59 | 0.794 40 | 22.91 | 36.52 | 137.39 |
| 10 | 283.15 | 50 | 1 227.2 | 0.007 658 | 0.801 76 | 0.811 63 | 27.94 | 47.23 | 175.54 |
| 15 | 288.15 | 59 | 1 704.4 | 0.010 69 | 0.816 00 | 0.829 98 | 32.97 | 59.97 | 220.22 |
| 20 | 293.15 | 68 | 2 337.2 | 0.014 75 | 0.830 17 | 0.849 83 | 38.00 | 75.42 | 273.32 |
| 25 | 298.15 | 77 | 3 167.0 | 0.020 16 | 0.844 34 | 0.871 62 | 43.03 | 94.38 | 337.39 |
| 30 | 303.15 | 86 | 4 242.8 | 0.027 31 | 0.858 51 | 0.896 09 | 48.07 | 117.8 | 415.65 |
| 35 | 308.15 | 95 | 5 623.4 | 0.036 73 | 0.872 74 | 0.924 06 | 53.10 | 147.3 | 512.17 |
| 40 | 313.15 | 104 | 7 377.6 | 0.049 11 | 0.886 92 | 0.956 65 | 58.14 | 184.5 | 532.31 |
| 45 | 318.15 | 113 | 9 584.8 | 0.065 36 | 0.901 15 | 0.995 35 | 63.17 | 232.0 | 783.06 |
| 50 | 323.15 | 122 | 12 339 | 0.086 78 | 0.915 32 | 1.042 3 | 68.21 | 293.1 | 975.27 |
| 55 | 328.15 | 131 | 15 745 | 0.115 2 | 0.929 49 | 1.100 7 | 73.25 | 372.9 | 1 221.5 |
| 60 | 333.15 | 140 | 19 925 | 0.153 4 | 0.943 72 | 1.174 8 | 78.29 | 478.5 | 1 543.5 |
| 65 | 338.15 | 149 | 25 014 | 0.205 5 | 0.957 90 | 1.272 1 | 83.33 | 621.4 | 1 973.6 |
| 70 | 343.15 | 158 | 31 167 | 0.278 8 | 0.972 07 | 1.404 2 | 88.38 | 820.5 | 2 564.8 |
| 75 | 348.15 | 167 | 38 554 | 0.385 8 | 0.986 30 | 1.592 4 | 93.42 | 1 110 | 3 412.8 |
| 80 | 353.15 | 176 | 47 365 | 0.551 9 | 1.000 5 | 1.879 1 | 98.47 | 1 557 | 4 710.9 |
| 85 | 358.15 | 185 | 57 809 | 0.836 3 | 1.014 6 | 2.363 2 | 103.5 | 2 321 | 6 892.6 |
| 90 | 363.15 | 194 | 70 112 | 1.416 | 1.028 8 | 3.340 9 | 108.6 | 3 876 | 11 281 |

*Note:* The $P_s$ column in this table gives the vapor pressure of pure water at temperature intervals of five degrees Celsius. For the latest data on vapor pressures at intervals of 0.1 deg C, from 0–100 deg C, see "Vapor Pressure Equation for Water", A. Wexler and L. Greenspan, *J. Res. Nat. Bur. Stand.*, 75A(3):213–229, May–June 1971.

[a]For very low barometric pressures and high wet-bulb temperatures, the values of $h_a$ in this table are somewhat low; for corrections see "ASHRAE Handbook of Fundamentals".

*Computed from: Psychrometric Tables, in "ASHRAE Handbook of Fundamentals", American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1972.

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**TABLE A.4 Water Vapor at Low Pressures: Perfect Gas Behavior pv/T = R = 0.461 51 kJ/kg·K**

## Symbols and Units:

$t$ = thermodynamic temperature, deg C
$T$ = thermodynamic temperature, K
$pv$ = $RT$, kJ/kg
$u_o$ = specific internal energy at zero pressure, kJ/kg
$h_o$ = specific enthalpy at zero pressure, kJ/kg
$s_l$ = specific entropy of semiperfect vapor at 0.1 MN/m$^2$, kJ/kg·K
$\psi_l$ = specific Helmholtz free energy of semiperfect vapor at 0.1 MN/m$^2$, kJ/kg
$\psi_l$ = specific Helmholtz free energy of semiperfect vapor at 0.1 MN/m$^2$, kJ/kg
$\zeta_l$ = specific Gibbs free energy of semiperfect vapor at 0.1 MN/m$^2$, kJ/kg
$p_r$ = relative pressure, pressure of semiperfect vapor at zero entropy, TN/m$^2$
$v_r$ = relative specific volume, specific volume of semiperfect vapor at zero entropy, mm$^3$/kg
$c_{po}$ = specific heat capacity at constant pressure for zero pressure, kJ/kg·K
$c_{vo}$ = specific heat capacity at constant volume for zero pressure, kJ/kg·K
$k$ = $c_{po}/c_{vo}$ = isentropic exponent, $-(\partial \log p/\partial \log v)_s$

| $t$ | $T$ | $pv$ | $u_o$ | $h_o$ | $s_l$ | $\psi_l$ | $\zeta_l$ | $p_r$ | $v_r$ | $c_{po}$ | $c_{vo}$ | $k$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 273.15 | 126.06 | 2 375.5 | 2 501.5 | 6.804 2 | 516.9 | 643.0 | .252 9 | 498.4 | 1.858 4 | 1.396 9 | 1.330 4 |
| 10 | 283.15 | 130.68 | 2 389.4 | 2 520.1 | 6.871 1 | 443.9 | 574.6 | .292 3 | 447.0 | 1.860 1 | 1.398 6 | 1.330 0 |
| 20 | 293.15 | 135.29 | 2 403.4 | 2 538.7 | 6.935 7 | 370.2 | 505.5 | .336 3 | 402.4 | 1.862 2 | 1.400 7 | 1.329 5 |
| 30 | 303.15 | 139.91 | 2 417.5 | 2 557.4 | 6.998 2 | 296.0 | 435.9 | .385 0 | 363.4 | 1.864 7 | 1.403 1 | 1.328 9 |
| 40 | 313.15 | 144.52 | 2 431.5 | 2 576.0 | 7.058 7 | 221.1 | 365.6 | .439 0 | 329.2 | 1.867 4 | 1.405 9 | 1.328 3 |
| 50 | 323.15 | 149.14 | 2 445.6 | 2 594.7 | 7.117 5 | 145.6 | 294.7 | .498 6 | 299.1 | 1.870 5 | 1.409 0 | 1.327 5 |
| 60 | 333.15 | 153.75 | 2 459.7 | 2 613.4 | 7.174 5 | 69.5 | 223.2 | .564 2 | 272.5 | 1.873 8 | 1.412 3 | 1.326 8 |
| 70 | 343.15 | 158.37 | 2 473.8 | 2 632.2 | 7.230 0 | −7.2 | 151.2 | .636 3 | 248.9 | 1.877 4 | 1.415 9 | 1.325 9 |
| 80 | 353.15 | 162.98 | 2 488.0 | 2 651.0 | 7.284 0 | −84.3 | 78.6 | .715 2 | 227.9 | 1.881 2 | 1.419 7 | 1.325 1 |
| 90 | 363.15 | 167.60 | 2 502.2 | 2 669.8 | 7.336 6 | −162.1 | 5.5 | .801 5 | 209.1 | 1.885 2 | 1.423 7 | 1.324 2 |
| 100 | 373.15 | 172.21 | 2 516.5 | 2 688.7 | 7.387 8 | −240.3 | −68.1 | .895 7 | 192.26 | 1.889 4 | 1.427 9 | 1.323 2 |
| 120 | 393.15 | 181.44 | 2 545.1 | 2 726.6 | 7.486 7 | −398.3 | −216.8 | 1.109 7 | 163.50 | 1.898 3 | 1.436 7 | 1.321 2 |
| 140 | 413.15 | 190.67 | 2 573.9 | 2 764.6 | 7.581 1 | −558.2 | −367.5 | 1.361 7 | 140.03 | 1.907 7 | 1.446 2 | 1.319 1 |
| 160 | 433.15 | 199.90 | 2 603.0 | 2 802.9 | 7.671 5 | −720.0 | −520.1 | 1.656 4 | 120.69 | 1.917 7 | 1.456 2 | 1.316 9 |
| 180 | 453.15 | 209.13 | 2 632.2 | 2 841.3 | 7.758 3 | −883.5 | −674.4 | 1.999 1 | 104.61 | 1.928 1 | 1.466 6 | 1.314 7 |
| 200 | 473.15 | 218.4 | 2 661.6 | 2 880.0 | 7.841 8 | −1 048.7 | −830.4 | 2.396 | 91.15 | 1.938 9 | 1.477 4 | 1.312 4 |
| 300 | 573.15 | 264.5 | 2 812.3 | 3 076.8 | 8.218 9 | −1 898.4 | −1 633.9 | 5.423 | 48.77 | 1.997 5 | 1.536 0 | 1.300 5 |
| 400 | 673.15 | 310.7 | 2 969.0 | 3 279.7 | 8.545 1 | −2 783.1 | −2 472.5 | 10.996 | 28.25 | 2.061 4 | 1.599 9 | 1.288 5 |
| 500 | 773.15 | 356.8 | 3 132.4 | 3 489.2 | 8.835 2 | −3 699 | −3 342 | 20.61 | 17.310 | 2.128 7 | 1.667 2 | 1.276 8 |
| 600 | 873.15 | 403.0 | 3 302.5 | 3 705.5 | 9.098 2 | −4 642 | −4 239 | 36.45 | 11.056 | 2.198 0 | 1.736 5 | 1.265 8 |
| 700 | 973.15 | 449.1 | 3 479.7 | 3 928.8 | 9.340 3 | −5 610 | −5 161 | 61.58 | 7.293 | 2.268 3 | 1.806 8 | 1.255 4 |
| 800 | 1 073.15 | 495.3 | 3 663.9 | 4 159.2 | 9.565 5 | −6 601 | −6 106 | 100.34 | 4.936 | 2.338 7 | 1.877 1 | 1.245 9 |
| 900 | 1 173.15 | 541.4 | 3 855.1 | 4 396.5 | 9.776 9 | −7 615 | −7 073 | 158.63 | 3.413 | 2.407 8 | 1.946 2 | 1.237 1 |
| 1 000 | 1 273.15 | 587.6 | 4 053.1 | 4 640.6 | 9.976 6 | −8 649 | −8 061 | 244.5 | 2.403 | 2.474 4 | 2.012 8 | 1.299 3 |
| 1 100 | 1 373.15 | 633.7 | 4 257.5 | 4 891.2 | 10.166 1 | −9 702 | −9 068 | 368.6 | 1.719 | 2.536 9 | 2.075 4 | 1.222 4 |
| 1 200 | 1 473.15 | 679.9 | 4 467.9 | 5 147.8 | 10.346 4 | −10 774 | −10 094 | 544.9 | 1.248 | 2.593 8 | 2.132 3 | 1.216 4 |
| 1 300 | 1 573.15 | 726.0 | 4 683.7 | 5 409.7 | 10.518 4 | −11 863 | −11 137 | 791.0 | .918 | 2.643 1 | 2.181 6 | 1.211 5 |

*Adapted from: "Steam Tables", J.H. Keenan, F.G. Keyes, P.G. Hill, and J.G. Moore, John Wiley & Sons, Inc., 1969 (International Edition—Metric Units).

**REFERENCE**

For other steam tables in metric units, see "Steam Tables in SI Units", Ministry of Technology, London, 1970.

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**TABLE A.5 Properties of Saturated Water and Steam**

## Part a. Temperature Table

| Temp. °C | Press. bars | Specific Volume $m^3/kg$ | | Internal Energy kJ/kg | | Enthalpy kJ/kg | | | Entropy kJ/kg · K | | Temp. °C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $v_f \times 10^3$ | Sat. Vapor $v_g$ | Sat. Liquid $u_f$ | Sat. Vapor $u_g$ | Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Sat. Liquid $s_f$ | Sat. Vapor $s_g$ | |
| .01 | 0.00611 | 1.0002 | 206.136 | 0.00 | 2375.3 | 0.01 | 2501.3 | 2501.4 | 0.0000 | 9.1562 | .01 |
| 4 | 0.00813 | 1.0001 | 157.232 | 16.77 | 2380.9 | 16.78 | 2491.9 | 2508.7 | 0.0610 | 9.0514 | 4 |
| 5 | 0.00872 | 1.0001 | 147.120 | 20.97 | 2382.3 | 20.98 | 2489.6 | 2510.6 | 0.0761 | 9.0257 | 5 |
| 6 | 0.00935 | 1.0001 | 137.734 | 25.19 | 2383.6 | 25.20 | 2487.2 | 2512.4 | 0.0912 | 9.0003 | 6 |
| 8 | 0.01072 | 1.0002 | 120.917 | 33.59 | 2386.4 | 33.60 | 2482.5 | 2516.1 | 0.1212 | 8.9501 | 8 |
| 10 | 0.01228 | 1.0004 | 106.379 | 42.00 | 2389.2 | 42.01 | 2477.7 | 2519.8 | 0.1510 | 8.9008 | 10 |
| 11 | 0.01312 | 1.0004 | 99.857 | 46.20 | 2390.5 | 46.20 | 2475.4 | 2521.6 | 0.1658 | 8.8765 | 11 |
| 12 | 0.01402 | 1.0005 | 93.784 | 50.41 | 2391.9 | 50.41 | 2473.0 | 2523.4 | 0.1806 | 8.8524 | 12 |
| 13 | 0.01497 | 1.0007 | 88.124 | 54.60 | 2393.3 | 54.60 | 2470.7 | 2525.3 | 0.1953 | 8.8285 | 13 |
| 14 | 0.01598 | 1.0008 | 82.848 | 58.79 | 2394.7 | 58.80 | 2468.3 | 2527.1 | 0.2099 | 8.8048 | 14 |
| 15 | 0.01705 | 1.0009 | 77.926 | 62.99 | 2396.1 | 62.99 | 2465.9 | 2528.9 | 0.2245 | 8.7814 | 15 |
| 16 | 0.01818 | 1.0011 | 73.333 | 67.18 | 2397.4 | 67.19 | 2463.6 | 2530.8 | 0.2390 | 8.7582 | 16 |
| 17 | 0.01938 | 1.0012 | 69.044 | 71.38 | 2398.8 | 71.38 | 2461.2 | 2532.6 | 0.2535 | 8.7351 | 17 |
| 18 | 0.02064 | 1.0014 | 65.038 | 75.57 | 2400.2 | 75.58 | 2458.8 | 2534.4 | 0.2679 | 8.7123 | 18 |
| 19 | 0.02198 | 1.0016 | 61.293 | 79.76 | 2401.6 | 79.77 | 2456.5 | 2536.2 | 0.2823 | 8.6897 | 19 |
| 20 | 0.02339 | 1.0018 | 57.791 | 83.95 | 2402.9 | 83.96 | 2454.1 | 2538.1 | 0.2966 | 8.6672 | 20 |
| 21 | 0.02487 | 1.0020 | 54.514 | 88.14 | 2404.3 | 88.14 | 2451.8 | 2539.9 | 0.3109 | 8.6450 | 21 |
| 22 | 0.02645 | 1.0022 | 51.447 | 92.32 | 2405.7 | 92.33 | 2449.4 | 2541.7 | 0.3251 | 8.6229 | 22 |
| 23 | 0.02810 | 1.0024 | 48.574 | 96.51 | 2407.0 | 96.52 | 2447.0 | 2543.5 | 0.3393 | 8.6011 | 23 |
| 24 | 0.02985 | 1.0027 | 45.883 | 100.70 | 2408.4 | 100.70 | 2444.7 | 2545.4 | 0.3534 | 8.5794 | 24 |
| 25 | 0.03169 | 1.0029 | 43.360 | 104.88 | 2409.8 | 104.89 | 2442.3 | 2547.2 | 0.3674 | 8.5580 | 25 |
| 26 | 0.03363 | 1.0032 | 40.994 | 109.06 | 2411.1 | 109.07 | 2439.9 | 2549.0 | 0.3814 | 8.5367 | 26 |
| 27 | 0.03567 | 1.0035 | 38.774 | 113.25 | 2412.5 | 113.25 | 2437.6 | 2550.8 | 0.3954 | 8.5156 | 27 |
| 28 | 0.03782 | 1.0037 | 36.690 | 117.42 | 2413.9 | 117.43 | 2435.2 | 2552.6 | 0.4093 | 8.4946 | 28 |
| 29 | 0.04008 | 1.0040 | 34.733 | 121.60 | 2415.2 | 121.61 | 2432.8 | 2554.5 | 0.4231 | 8.4739 | 29 |
| 30 | 0.04246 | 1.0043 | 32.894 | 125.78 | 2416.6 | 125.79 | 2430.5 | 2556.3 | 0.4369 | 8.4533 | 30 |
| 31 | 0.04496 | 1.0046 | 31.165 | 129.96 | 2418.0 | 129.97 | 2428.1 | 2558.1 | 0.4507 | 8.4329 | 31 |
| 32 | 0.04759 | 1.0050 | 29.540 | 134.14 | 2419.3 | 134.15 | 2425.7 | 2559.9 | 0.4644 | 8.4127 | 32 |
| 33 | 0.05034 | 1.0053 | 28.011 | 138.32 | 2420.7 | 138.33 | 2423.4 | 2561.7 | 0.4781 | 8.3927 | 33 |
| 34 | 0.05324 | 1.0056 | 26.571 | 142.50 | 2422.0 | 142.50 | 2421.0 | 2563.5 | 0.4917 | 8.3728 | 34 |
| 35 | 0.05628 | 1.0060 | 25.216 | 146.67 | 2423.4 | 146.68 | 2418.6 | 2565.3 | 0.5053 | 8.3531 | 35 |
| 36 | 0.05947 | 1.0063 | 23.940 | 150.85 | 2424.7 | 150.86 | 2416.2 | 2567.1 | 0.5188 | 8.3336 | 36 |
| 38 | 0.06632 | 1.0071 | 21.602 | 159.20 | 2427.4 | 159.21 | 2411.5 | 2570.7 | 0.5458 | 8.2950 | 38 |
| 40 | 0.07384 | 1.0078 | 19.523 | 167.56 | 2430.1 | 167.57 | 2406.7 | 2574.3 | 0.5725 | 8.2570 | 40 |
| 45 | 0.09593 | 1.0099 | 15.258 | 188.44 | 2436.8 | 188.45 | 2394.8 | 2583.2 | 0.6387 | 8.1648 | 45 |

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**TABLE A.5 (continued) Properties of Saturated Water and Steam**

| Temp. °C | Press. bars | Specific Volume $m^3/kg$ | | Internal Energy kJ/kg | | Enthalpy kJ/kg | | | Entropy kJ/kg · K | | Temp. °C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $v_f \times 10^3$ | Sat. Vapor $v_g$ | Sat. Liquid $u_f$ | Sat. Vapor $u_g$ | Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Sat. Liquid $s_f$ | Sat. Vapor $s_g$ | |
| 50 | .1235 | 1.0121 | 12.032 | 209.32 | 2443.5 | 209.33 | 2382.7 | 2592.1 | .7038 | 8.0763 | 50 |
| 55 | .1576 | 1.0146 | 9.568 | 230.21 | 2450.1 | 230.23 | 2370.7 | 2600.9 | .7679 | 7.9913 | 55 |
| 60 | .1994 | 1.0172 | 7.671 | 251.11 | 2456.6 | 251.13 | 2358.5 | 2609.6 | .8312 | 7.9096 | 60 |
| 65 | .2503 | 1.0199 | 6.197 | 272.02 | 2463.1 | 272.06 | 2346.2 | 2618.3 | .8935 | 7.8310 | 65 |
| 70 | .3119 | 1.0228 | 5.042 | 292.95 | 2469.6 | 292.98 | 2333.8 | 2626.8 | .9549 | 7.7553 | 70 |
| 75 | .3858 | 1.0259 | 4.131 | 313.90 | 2475.9 | 313.93 | 2321.4 | 2635.3 | 1.0155 | 7.6824 | 75 |
| 80 | .4739 | 1.0291 | 3.407 | 334.86 | 2482.2 | 334.91 | 2308.8 | 2643.7 | 1.0753 | 7.6122 | 80 |
| 85 | .5783 | 1.0325 | 2.828 | 355.84 | 2488.4 | 355.90 | 2296.0 | 2651.9 | 1.1343 | 7.5445 | 85 |
| 90 | .7014 | 1.0360 | 2.361 | 376.85 | 2494.5 | 376.92 | 2283.2 | 2660.1 | 1.1925 | 7.4791 | 90 |
| 95 | .8455 | 1.0397 | 1.982 | 397.88 | 2500.6 | 397.96 | 2270.2 | 2668.1 | 1.2500 | 7.4159 | 95 |
| 100 | 1.014 | 1.0435 | 1.673 | 418.94 | 2506.5 | 419.04 | 2257.0 | 2676.1 | 1.3069 | 7.3549 | 100 |
| 110 | 1.433 | 1.0516 | 1.210 | 461.14 | 2518.1 | 461.30 | 2230.2 | 2691.5 | 1.4185 | 7.2387 | 110 |
| 120 | 1.985 | 1.0603 | 0.8919 | 503.50 | 2529.3 | 503.71 | 2202.6 | 2706.3 | 1.5276 | 7.1296 | 120 |
| 130 | 2.701 | 1.0697 | 0.6685 | 546.02 | 2539.9 | 546.31 | 2174.2 | 2720.5 | 1.6344 | 7.0269 | 130 |
| 140 | 3.613 | 1.0797 | 0.5089 | 588.74 | 2550.0 | 589.13 | 2144.7 | 2733.9 | 1.7391 | 6.9299 | 140 |
| 150 | 4.758 | 1.0905 | 0.3928 | 631.68 | 2559.5 | 632.20 | 2114.3 | 2746.5 | 1.8418 | 6.8379 | 150 |
| 160 | 6.178 | 1.1020 | 0.3071 | 674.86 | 2568.4 | 675.55 | 2082.6 | 2758.1 | 1.9427 | 6.7502 | 160 |
| 170 | 7.917 | 1.1143 | 0.2428 | 718.33 | 2576.5 | 719.21 | 2049.5 | 2768.7 | 2.0419 | 6.6663 | 170 |
| 180 | 10.02 | 1.1274 | 0.1941 | 762.09 | 2583.7 | 763.22 | 2015.0 | 2778.2 | 2.1396 | 6.5857 | 180 |
| 190 | 12.54 | 1.1414 | 0.1565 | 806.19 | 2590.0 | 807.62 | 1978.8 | 2786.4 | 2.2359 | 6.5079 | 190 |
| 200 | 15.54 | 1.1565 | 0.1274 | 850.65 | 2595.3 | 852.45 | 1940.7 | 2793.2 | 2.3309 | 6.4323 | 200 |
| 210 | 19.06 | 1.1726 | 0.1044 | 895.53 | 2599.5 | 897.76 | 1900.7 | 2798.5 | 2.4248 | 6.3585 | 210 |
| 220 | 23.18 | 1.1900 | 0.08619 | 940.87 | 2602.4 | 943.62 | 1858.5 | 2802.1 | 2.5178 | 6.2861 | 220 |
| 230 | 27.95 | 1.2088 | 0.07158 | 986.74 | 2603.9 | 990.12 | 1813.8 | 2804.0 | 2.6099 | 6.2146 | 230 |
| 240 | 33.44 | 1.2291 | 0.05976 | 1033.2 | 2604.0 | 1037.3 | 1766.5 | 2803.8 | 2.7015 | 6.1437 | 240 |
| 250 | 39.73 | 1.2512 | 0.05013 | 1080.4 | 2602.4 | 1085.4 | 1716.2 | 2801.5 | 2.7927 | 6.0730 | 250 |
| 260 | 46.88 | 1.2755 | 0.04221 | 1128.4 | 2599.0 | 1134.4 | 1662.5 | 2796.6 | 2.8838 | 6.0019 | 260 |
| 270 | 54.99 | 1.3023 | 0.03564 | 1177.4 | 2593.7 | 1184.5 | 1605.2 | 2789.7 | 2.9751 | 5.9301 | 270 |
| 280 | 64.12 | 1.3321 | 0.03017 | 1227.5 | 2586.1 | 1236.0 | 1543.6 | 2779.6 | 3.0668 | 5.8571 | 280 |
| 290 | 74.36 | 1.3656 | 0.02557 | 1278.9 | 2576.0 | 1289.1 | 1477.1 | 2766.2 | 3.1594 | 5.7821 | 290 |
| 300 | 85.81 | 1.4036 | 0.02167 | 1332.0 | 2563.0 | 1344.0 | 1404.9 | 2749.0 | 3.2534 | 5.7045 | 300 |
| 320 | 112.7 | 1.4988 | 0.01549 | 1444.6 | 2525.5 | 1461.5 | 1238.6 | 2700.1 | 3.4480 | 5.5362 | 320 |
| 340 | 145.9 | 1.6379 | 0.01080 | 1570.3 | 2464.6 | 1594.2 | 1027.9 | 2622.0 | 3.6594 | 5.3357 | 340 |
| 360 | 186.5 | 1.8925 | 0.006945 | 1725.2 | 2351.5 | 1760.5 | 720.5 | 2481.0 | 3.9147 | 5.0526 | 360 |
| 374.14 | 220.9 | 3.155 | 0.003155 | 2029.6 | 2029.6 | 2099.3 | 0 | 2099.3 | 4.4298 | 4.4298 | 374.14 |

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**TABLE A.5 (continued) Properties of Saturated Water and Steam**

## Part b. Pressure Table

| Press. bars | Temp. °C | Specific Volume $m^3/kg$ | | Internal Energy kJ/kg | | Enthalpy kJ/kg | | | Entropy kJ/kg · K | | Press. bars |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $v_f \times 10^3$ | Sat. Vapor $v_g$ | Sat. Liquid $u_f$ | Sat. Vapor $u_g$ | Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Sat. Liquid $s_f$ | Sat. Vapor $s_g$ | |
| 0.04 | 28.96 | 1.0040 | 34.800 | 121.45 | 2415.2 | 121.46 | 2432.9 | 2554.4 | 0.4226 | 8.4746 | 0.04 |
| 0.06 | 36.16 | 1.0064 | 23.739 | 151.53 | 2425.0 | 151.53 | 2415.9 | 2567.4 | 0.5210 | 8.3304 | 0.06 |
| 0.08 | 41.51 | 1.0084 | 18.103 | 173.87 | 2432.2 | 173.88 | 2403.1 | 2577.0 | 0.5926 | 8.2287 | 0.08 |
| 0.10 | 45.81 | 1.0102 | 14.674 | 191.82 | 2437.9 | 191.83 | 2392.8 | 2584.7 | 0.6493 | 8.1502 | 0.10 |
| 0.20 | 60.06 | 1.0172 | 7.649 | 251.38 | 2456.7 | 251.40 | 2358.3 | 2609.7 | 0.8320 | 7.9085 | 0.20 |
| 0.30 | 69.10 | 1.0223 | 5.229 | 289.20 | 2468.4 | 289.23 | 2336.1 | 2625.3 | 0.9439 | 7.7686 | 0.30 |
| 0.40 | 75.87 | 1.0265 | 3.993 | 317.53 | 2477.0 | 317.58 | 2319.2 | 2636.8 | 1.0259 | 7.6700 | 0.40 |
| 0.50 | 81.33 | 1.0300 | 3.240 | 340.44 | 2483.9 | 340.49 | 2305.4 | 2645.9 | 1.0910 | 7.5939 | 0.50 |
| 0.60 | 85.94 | 1.0331 | 2.732 | 359.79 | 2489.6 | 359.86 | 2293.6 | 2653.5 | 1.1453 | 7.5320 | 0.60 |
| 0.70 | 89.95 | 1.0360 | 2.365 | 376.63 | 2494.5 | 376.70 | 2283.3 | 2660.0 | 1.1919 | 7.4797 | 0.70 |
| 0.80 | 93.50 | 1.0380 | 2.087 | 391.58 | 2498.8 | 391.66 | 2274.1 | 2665.8 | 1.2329 | 7.4346 | 0.80 |
| 0.90 | 96.71 | 1.0410 | 1.869 | 405.06 | 2502.6 | 405.15 | 2265.7 | 2670.9 | 1.2695 | 7.3949 | 0.90 |
| 1.00 | 99.63 | 1.0432 | 1.694 | 417.36 | 2506.1 | 417.46 | 2258.0 | 2675.5 | 1.3026 | 7.3594 | 1.00 |
| 1.50 | 111.4 | 1.0528 | 1.159 | 466.94 | 2519.7 | 467.11 | 2226.5 | 2693.6 | 1.4336 | 7.2233 | 1.50 |
| 2.00 | 120.2 | 1.0605 | 0.8857 | 504.49 | 2529.5 | 504.70 | 2201.9 | 2706.7 | 1.5301 | 7.1271 | 2.00 |
| 2.50 | 127.4 | 1.0672 | 0.7187 | 535.10 | 2537.2 | 535.37 | 2181.5 | 2716.9 | 1.6072 | 7.0527 | 2.50 |
| 3.00 | 133.6 | 1.0732 | 0.6058 | 561.15 | 2543.6 | 561.47 | 2163.8 | 2725.3 | 1.6718 | 6.9919 | 3.00 |
| 3.50 | 138.9 | 1.0786 | 0.5243 | 583.95 | 2546.9 | 584.33 | 2148.1 | 2732.4 | 1.7275 | 6.9405 | 3.50 |
| 4.00 | 143.6 | 1.0836 | 0.4625 | 604.31 | 2553.6 | 604.74 | 2133.8 | 2738.6 | 1.7766 | 6.8959 | 4.00 |
| 4.50 | 147.9 | 1.0882 | 0.4140 | 622.25 | 2557.6 | 623.25 | 2120.7 | 2743.9 | 1.8207 | 6.8565 | 4.50 |
| 5.00 | 151.9 | 1.0926 | 0.3749 | 639.68 | 2561.2 | 640.23 | 2108.5 | 2748.7 | 1.8607 | 6.8212 | 5.00 |
| 6.00 | 158.9 | 1.1006 | 0.3157 | 669.90 | 2567.4 | 670.56 | 2086.3 | 2756.8 | 1.9312 | 6.7600 | 6.00 |
| 7.00 | 165.0 | 1.1080 | 0.2729 | 696.44 | 2572.5 | 697.22 | 2066.3 | 2763.5 | 1.9922 | 6.7080 | 7.00 |
| 8.00 | 170.4 | 1.1148 | 0.2404 | 720.22 | 2576.8 | 721.11 | 2048.0 | 2769.1 | 2.0462 | 6.6628 | 8.00 |
| 9.00 | 175.4 | 1.1212 | 0.2150 | 741.83 | 2580.5 | 742.83 | 2031.1 | 2773.9 | 2.0946 | 6.6226 | 9.00 |
| 10.0 | 179.9 | 1.1273 | 0.1944 | 761.68 | 2583.6 | 762.81 | 2015.3 | 2778.1 | 2.1387 | 6.5863 | 10.0 |
| 15.0 | 198.3 | 1.1539 | 0.1318 | 843.16 | 2594.5 | 844.84 | 1947.3 | 2792.2 | 2.3150 | 6.4448 | 15.0 |
| 20.0 | 212.4 | 1.1767 | 0.09963 | 906.44 | 2600.3 | 908.79 | 1890.7 | 2799.5 | 2.4474 | 6.3409 | 20.0 |
| 25.0 | 224.0 | 1.1973 | 0.07998 | 959.11 | 2603.1 | 962.11 | 1841.0 | 2803.1 | 2.5547 | 6.2575 | 25.0 |
| 30.0 | 233.9 | 1.2165 | 0.06668 | 1004.8 | 2604.1 | 1008.4 | 1795.7 | 2804.2 | 2.6457 | 6.1869 | 30.0 |
| 35.0 | 242.6 | 1.2347 | 0.05707 | 1045.4 | 2603.7 | 1049.8 | 1753.7 | 2803.4 | 2.7253 | 6.1253 | 35.0 |
| 40.0 | 250.4 | 1.2522 | 0.04978 | 1082.3 | 2602.3 | 1087.3 | 1714.1 | 2801.4 | 2.7964 | 6.0701 | 40.0 |
| 45.0 | 257.5 | 1.2692 | 0.04406 | 1116.2 | 2600.1 | 1121.9 | 1676.4 | 2798.3 | 2.8610 | 6.0199 | 45.0 |
| 50.0 | 264.0 | 1.2859 | 0.03944 | 1147.8 | 2597.1 | 1154.2 | 1640.1 | 2794.3 | 2.9202 | 5.9734 | 50.0 |
| 60.0 | 275.6 | 1.3187 | 0.03244 | 1205.4 | 2589.7 | 1213.4 | 1571.0 | 2784.3 | 3.0267 | 5.8892 | 60.0 |
| 70.0 | 285.9 | 1.3513 | 0.02737 | 1257.6 | 2580.5 | 1267.0 | 1505.1 | 2772.1 | 3.1211 | 5.8133 | 70.0 |
| 80.0 | 295.1 | 1.3842 | 0.02352 | 1305.6 | 2569.8 | 1316.6 | 1441.3 | 2758.0 | 3.2068 | 5.7432 | 80.0 |
| 90.0 | 303.4 | 1.4178 | 0.02048 | 1350.5 | 2557.8 | 1363.3 | 1378.9 | 2742.1 | 3.2858 | 5.6772 | 90.0 |
| 100. | 311.1 | 1.4524 | 0.01803 | 1393.0 | 2544.4 | 1407.6 | 1317.1 | 2724.7 | 3.3596 | 5.6141 | 100. |
| 110. | 318.2 | 1.4886 | 0.01599 | 1433.7 | 2529.8 | 1450.1 | 1255.5 | 2705.6 | 3.4295 | 5.5527 | 110. |
| 120. | 324.8 | 1.5267 | 0.01426 | 1473.0 | 2513.7 | 1491.3 | 1193.6 | 2684.9 | 3.4962 | 5.4924 | 120. |
| 130. | 330.9 | 1.5671 | 0.01278 | 1511.1 | 2496.1 | 1531.5 | 1130.7 | 2662.2 | 3.5606 | 5.4323 | 130. |
| 140. | 336.8 | 1.6107 | 0.01149 | 1548.6 | 2476.8 | 1571.1 | 1066.5 | 2637.6 | 3.6232 | 5.3717 | 140. |
| 150. | 342.2 | 1.6581 | 0.01034 | 1585.6 | 2455.5 | 1610.5 | 1000.0 | 2610.5 | 3.6848 | 5.3098 | 150. |
| 160. | 347.4 | 1.7107 | 0.009306 | 1622.7 | 2431.7 | 1650.1 | 930.6 | 2580.6 | 3.7461 | 5.2455 | 160. |
| 170. | 352.4 | 1.7702 | 0.008364 | 1660.2 | 2405.0 | 1690.3 | 856.9 | 2547.2 | 3.8079 | 5.1777 | 170. |
| 180. | 357.1 | 1.8397 | 0.007489 | 1698.9 | 2374.3 | 1732.0 | 777.1 | 2509.1 | 3.8715 | 5.1044 | 180. |
| 190. | 361.5 | 1.9243 | 0.006657 | 1739.9 | 2338.1 | 1776.5 | 688.0 | 2464.5 | 3.9388 | 5.0228 | 190. |
| 200. | 365.8 | 2.036 | 0.005834 | 1785.6 | 2293.0 | 1826.3 | 583.4 | 2409.7 | 4.0139 | 4.9269 | 200. |
| 220.9 | 374.1 | 3.155 | 0.003155 | 2029.6 | 2029.6 | 2099.3 | 0 | 2099.3 | 4.4298 | 4.4298 | 220.9 |

*Source:* Adapted from M.J. Moran and H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, 3rd. ed., Wiley, New York, 1995, as extracted from J.H. Keenan, F.G. Keyes, P.G. Hill, and J.G. Moore, *Steam Tables*, Wiley, New York, 1969.

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**TABLE A.6 Properties of Superheated Steam**

## Symbols and Units:

$T$ = temperature, °C
$T_{sat}$ = Saturation temperature, °C
$\nu$ = Specific volume, $m^3/kg$
$u$ = internal energy, kJ/kg
$h$ = enthalpy, kJ/kg
$S$ = entropy, kJ/kg·K
$p$ = pressure, bar and μPa

| $T$ °C | $v$ $m^3/kg$ | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ $m^3/kg$ | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|---|---|---|---|
| | $p$ = 0.06 bar = 0.006 MPa ($T_{sat}$ = 36.16°C) | | | | $p$ = 0.35 bar = 0.035 MPa ($T_{sat}$ = 72.69°C) | | | |
| Sat. | 23.739 | 2425.0 | 2567.4 | 8.3304 | 4.526 | 2473.0 | 2631.4 | 7.7158 |
| 80 | 27.132 | 2487.3 | 2650.1 | 8.5804 | 4.625 | 2483.7 | 2645.6 | 7.7564 |
| 120 | 30.219 | 2544.7 | 2726.0 | 8.7840 | 5.163 | 2542.4 | 2723.1 | 7.9644 |
| 160 | 33.302 | 2602.7 | 2802.5 | 8.9693 | 5.696 | 2601.2 | 2800.6 | 8.1519 |
| 200 | 36.383 | 2661.4 | 2879.7 | 9.1398 | 6.228 | 2660.4 | 2878.4 | 8.3237 |
| 240 | 39.462 | 2721.0 | 2957.8 | 9.2982 | 6.758 | 2720.3 | 2956.8 | 8.4828 |
| 280 | 42.540 | 2781.5 | 3036.8 | 9.4464 | 7.287 | 2780.9 | 3036.0 | 8.6314 |
| 320 | 45.618 | 2843.0 | 3116.7 | 9.5859 | 7.815 | 2842.5 | 3116.1 | 8.7712 |
| 360 | 48.696 | 2905.5 | 3197.7 | 9.7180 | 8.344 | 2905.1 | 3197.1 | 8.9034 |
| 400 | 51.774 | 2969.0 | 3279.6 | 9.8435 | 8.872 | 2968.6 | 3279.2 | 9.0291 |
| 440 | 54.851 | 3033.5 | 3362.6 | 9.9633 | 9.400 | 3033.2 | 3362.2 | 9.1490 |
| 500 | 59.467 | 3132.3 | 3489.1 | 10.1336 | 10.192 | 3132.1 | 3488.8 | 9.3194 |
| | $p$ = 0.70 bar = 0.07 MPa ($T_{sat}$ = 89.95°C) | | | | $p$ = 1.0 bar = 0.10 MPa ($T_{sat}$ = 99.63°C) | | | |
| Sat. | 2.365 | 2494.5 | 2660.0 | 7.4797 | 1.694 | 2506.1 | 2675.5 | 7.3594 |
| 100 | 2.434 | 2509.7 | 2680.0 | 7.5341 | 1.696 | 2506.7 | 2676.2 | 7.3614 |
| 120 | 2.571 | 2539.7 | 2719.6 | 7.6375 | 1.793 | 2537.3 | 2716.6 | 7.4668 |
| 160 | 2.841 | 2599.4 | 2798.2 | 7.8279 | 1.984 | 2597.8 | 2796.2 | 7.6597 |
| 200 | 3.108 | 2659.1 | 2876.7 | 8.0012 | 2.172 | 2658.1 | 2875.3 | 7.8343 |
| 240 | 3.374 | 2719.3 | 2955.5 | 8.1611 | 2.359 | 2718.5 | 2954.5 | 7.9949 |
| 280 | 3.640 | 2780.2 | 3035.0 | 8.3162 | 2.546 | 2779.6 | 3034.2 | 8.1445 |
| 320 | 3.905 | 2842.0 | 3115.3 | 8.4504 | 2.732 | 2841.5 | 3114.6 | 8.2849 |
| 360 | 4.170 | 2904.6 | 3196.5 | 8.5828 | 2.917 | 2904.2 | 3195.9 | 8.4175 |
| 400 | 4.434 | 2968.2 | 3278.6 | 8.7086 | 3.103 | 2967.9 | 3278.2 | 8.5435 |
| 440 | 4.698 | 3032.9 | 3361.8 | 8.8286 | 3.288 | 3032.6 | 3361.4 | 8.6636 |
| 500 | 5.095 | 3131.8 | 3488.5 | 8.9991 | 3.565 | 3131.6 | 3488.1 | 8.8342 |
| | $p$ = 1.5 bars = 0.15 MPa ($T_{sat}$ = 111.37°C) | | | | $p$ = 3.0 bars = 0.30 MPa ($T_{sat}$ = 133.55°C) | | | |
| Sat. | 1.159 | 2519.7 | 2693.6 | 7.2233 | 0.606 | 2543.6 | 2725.3 | 6.9919 |
| 120 | 1.188 | 2533.3 | 2711.4 | 7.2693 | | | | |
| 160 | 1.317 | 2595.2 | 2792.8 | 7.4665 | 0.651 | 2587.1 | 2782.3 | 7.1276 |
| 200 | 1.444 | 2656.2 | 2872.9 | 7.6433 | 0.716 | 2650.7 | 2865.5 | 7.3115 |
| 240 | 1.570 | 2717.2 | 2952.7 | 7.8052 | 0.781 | 2713.1 | 2947.3 | 7.4774 |
| 280 | 1.695 | 2778.6 | 3032.8 | 7.9555 | 0.844 | 2775.4 | 3028.6 | 7.6299 |
| 320 | 1.819 | 2840.6 | 3113.5 | 8.0964 | 0.907 | 2838.1 | 3110.1 | 7.7722 |
| 360 | 1.943 | 2903.5 | 3195.0 | 8.2293 | 0.969 | 2901.4 | 3192.2 | 7.9061 |
| 400 | 2.067 | 2967.3 | 3277.4 | 8.3555 | 1.032 | 2965.6 | 3275.0 | 8.0330 |
| 440 | 2.191 | 3032.1 | 3360.7 | 8.4757 | 1.094 | 3030.6 | 3358.7 | 8.1538 |
| 500 | 2.376 | 3131.2 | 3487.6 | 8.6466 | 1.187 | 3130.0 | 3486.0 | 8.3251 |
| 600 | 2.685 | 3301.7 | 3704.3 | 8.9101 | 1.341 | 3300.8 | 3703.2 | 8.5892 |

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**TABLE A.6 (continued) Properties of Superheated Steam**

## Symbols and Units:

$T$ = temperature, °C
$T_{sat}$ = Saturation temperature, °C
$\nu$ = Specific volume, $m^3/kg$
$u$ = internal energy, kJ/kg
$h$ = enthalpy, kJ/kg
$S$ = entropy, kJ/kg·K
$p$ = pressure, bar and μPa

| $T$ °C | $v$ $m^3/kg$ | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ $m^3/kg$ | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg . k |
|---|---|---|---|---|---|---|---|---|
| | $p$ = 5.0 bars = 0.50 MPa ($T_{sat}$ = 151.86°C) | | | | $p$ = 7.0 bars = 0.70 MPa ($T_{sat}$ = 164.97°C) | | | |
| Sat. | 0.3749 | 2561.2 | 2748.7 | 6.8213 | 0.2729 | 2572.5 | 2763.5 | 6.7080 |
| 180 | 0.4045 | 2609.7 | 2812.0 | 6.9656 | 0.2847 | 2599.8 | 2799.1 | 6.7880 |
| 200 | 0.4249 | 2642.9 | 2855.4 | 7.0592 | 0.2999 | 2634.8 | 2844.8 | 6.8865 |
| 240 | 0.4646 | 2707.6 | 2939.9 | 7.2307 | 0.3292 | 2701.8 | 2932.2 | 7.0641 |
| 280 | 0.5034 | 2771.2 | 3022.9 | 7.3865 | 0.3574 | 2766.9 | 3017.1 | 7.2233 |
| 320 | 0.5416 | 2834.7 | 3105.6 | 7.5308 | 0.3852 | 2831.3 | 3100.9 | 7.3697 |
| 360 | 0.5796 | 2898.7 | 3188.4 | 7.6660 | 0.4126 | 2895.8 | 3184.7 | 7.5063 |
| 400 | 0.6173 | 2963.2 | 3271.9 | 7.7938 | 0.4397 | 2960.9 | 3268.7 | 7.6350 |
| 440 | 0.6548 | 3028.6 | 3356.0 | 7.9152 | 0.4667 | 3026.6 | 3353.3 | 7.7571 |
| 500 | 0.7109 | 3128.4 | 3483.9 | 8.0873 | 0.5070 | 3126.8 | 3481.7 | 7.9299 |
| 600 | 0.8041 | 3299.6 | 3701.7 | 8.3522 | 0.5738 | 3298.5 | 3700.2 | 8.1956 |
| 700 | 0.8969 | 3477.5 | 3925.9 | 8.5952 | 0.6403 | 3476.6 | 3924.8 | 8.4391 |
| | $p$ = 10.0 bars = 1.0 MPa ($T_{sat}$ = 179.91°C) | | | | $p$ = 15.0 bars = 1.5 MPa ($T_{sat}$ = 198.32°C) | | | |
| Sat. | 0.1944 | 2583.6 | 2778.1 | 6.5865 | 0.1318 | 2594.5 | 2792.2 | 6.4448 |
| 200 | 0.2060 | 2621.9 | 2827.9 | 6.6940 | 0.1325 | 2598.1 | 2796.8 | 6.4546 |
| 240 | 0.2275 | 2692.9 | 2920.4 | 6.8817 | 0.1483 | 2676.9 | 2899.3 | 6.6628 |
| 280 | 0.2480 | 2760.2 | 3008.2 | 7.0465 | 0.1627 | 2748.6 | 2992.7 | 6.8381 |
| 320 | 0.2678 | 2826.1 | 3093.9 | 7.1962 | 0.1765 | 2817.1 | 3081.9 | 6.9938 |
| 360 | 0.2873 | 2891.6 | 3178.9 | 7.3349 | 0.1899 | 2884.4 | 3169.2 | 7.1363 |
| 400 | 0.3066 | 2957.3 | 3263.9 | 7.4651 | 0.2030 | 2951.3 | 3255.8 | 7.2690 |
| 440 | 0.3257 | 3023.6 | 3349.3 | 7.5883 | 0.2160 | 3018.5 | 3342.5 | 7.3940 |
| 500 | 0.3541 | 3124.4 | 3478.5 | 7.7622 | 0.2352 | 3120.3 | 3473.1 | 7.5698 |
| 540 | 0.3729 | 3192.6 | 3565.6 | 7.8720 | 0.2478 | 3189.1 | 3560.9 | 7.6805 |
| 600 | 0.4011 | 3296.8 | 3697.9 | 8.0290 | 0.2668 | 3293.9 | 3694.0 | 7.8385 |
| 640 | 0.4198 | 3367.4 | 3787.2 | 8.1290 | 0.2793 | 3364.8 | 3783.8 | 7.9391 |
| | $p$ = 20.0 bars = 2.0 MPa ($T_{sat}$ = 212.42°C) | | | | $p$ = 30.0 bars = 3.0 MPa ($T_{sat}$ = 233.90°C) | | | |
| Sat. | 0.0996 | 2600.3 | 2799.5 | 6.3409 | 0.0667 | 2604.1 | 2804.2 | 6.1869 |
| 240 | 0.1085 | 2659.6 | 2876.5 | 6.4952 | 0.0682 | 2619.7 | 2824.3 | 6.2265 |
| 280 | 0.1200 | 2736.4 | 2976.4 | 6.6828 | 0.0771 | 2709.9 | 2941.3 | 6.4462 |
| 320 | 0.1308 | 2807.9 | 3069.5 | 6.8452 | 0.0850 | 2788.4 | 3043.4 | 6.6245 |
| 360 | 0.1411 | 2877.0 | 3159.3 | 6.9917 | 0.0923 | 2861.7 | 3138.7 | 6.7801 |
| 400 | 0.1512 | 2945.2 | 3247.6 | 7.1271 | 0.0994 | 2932.8 | 3230.9 | 6.9212 |
| 440 | 0.1611 | 3013.4 | 3335.5 | 7.2540 | 0.1062 | 3002.9 | 3321.5 | 7.0520 |
| 500 | 0.1757 | 3116.2 | 3467.6 | 7.4317 | 0.1162 | 3108.0 | 3456.5 | 7.2338 |
| 540 | 0.1853 | 3185.6 | 3556.1 | 7.5434 | 0.1227 | 3178.4 | 3546.6 | 7.3474 |
| 600 | 0.1996 | 3290.9 | 3690.1 | 7.7024 | 0.1324 | 3285.0 | 3682.3 | 7.5085 |
| 640 | 0.2091 | 3362.2 | 3780.4 | 7.8035 | 0.1388 | 3357.0 | 3773.5 | 7.6106 |
| 700 | 0.2232 | 3470.9 | 3917.4 | 7.9487 | 0.1484 | 3466.5 | 3911.7 | 7.7571 |

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**TABLE A.6 (continued) Properties of Superheated Steam**

## Symbols and Units:

$T$ = temperature, °C
$T_{sat}$ = Saturation temperature, °C
$v$ = Specific volume, $m^3/kg$
$u$ = internal energy, kJ/kg
$h$ = enthalpy, kJ/kg
$S$ = entropy, kJ/kg·K
$p$ = pressure, bar and μPa

| $T$ °C | $v$ $m^3/kg$ | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ $m^3/kg$ | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|---|---|---|---|
| | **$p$ = 40 bars = 4.0 MPa ($T_{sat}$ = 250.4°C)** | | | | **$p$ = 60 bars = 6.0 MPa ($T_{sat}$ = 275.64°C)** | | | |
| Sat. | 0.04978 | 2602.3 | 2801.4 | 6.0701 | 0.03244 | 2589.7 | 2784.3 | 5.8892 |
| 280 | 0.05546 | 2680.0 | 2901.8 | 6.2568 | 0.03317 | 2605.2 | 2804.2 | 5.9252 |
| 320 | 0.06199 | 2767.4 | 3015.4 | 6.4553 | 0.03876 | 2720.0 | 2952.6 | 6.1846 |
| 360 | 0.06788 | 2845.7 | 3117.2 | 6.6215 | 0.04331 | 2811.2 | 3071.1 | 6.3782 |
| 400 | 0.07341 | 2919.9 | 3213.6 | 6.7690 | 0.04739 | 2892.9 | 3177.2 | 6.5408 |
| 440 | 0.07872 | 2992.2 | 3307.1 | 6.9041 | 0.05122 | 2970.0 | 3277.3 | 6.6853 |
| 500 | 0.08643 | 3099.5 | 3445.3 | 7.0901 | 0.05665 | 3082.2 | 3422.2 | 6.8803 |
| 540 | 0.09145 | 3171.1 | 3536.9 | 7.2056 | 0.06015 | 3156.1 | 3517.0 | 6.9999 |
| 600 | 0.09885 | 3279.1 | 3674.4 | 7.3688 | 0.06525 | 3266.9 | 3658.4 | 7.1677 |
| 640 | 0.1037 | 3351.8 | 3766.6 | 7.4720 | 0.06859 | 3341.0 | 3752.6 | 7.2731 |
| 700 | 0.1110 | 3462.1 | 3905.9 | 7.6198 | 0.07352 | 3453.1 | 3894.1 | 7.4234 |
| 740 | 0.1157 | 3536.6 | 3999.6 | 7.7141 | 0.07677 | 3528.3 | 3989.2 | 7.5190 |
| | **$p$ = 80 bars = 8.0 MPa ($T_{sat}$ = 295.06°C)** | | | | **$p$ = 100 bars = 10.0 MPa ($T_{sat}$ = 311.06°C)** | | | |
| Sat. | 0.02352 | 2569.8 | 2758.0 | 5.7432 | 0.01803 | 2544.4 | 2724.7 | 5.6141 |
| 320 | 0.02682 | 2662.7 | 2877.2 | 5.9489 | 0.01925 | 2588.8 | 2781.3 | 5.7103 |
| 360 | 0.03089 | 2772.7 | 3019.8 | 6.1819 | 0.02331 | 2729.1 | 2962.1 | 6.0060 |
| 400 | 0.03432 | 2863.8 | 3138.3 | 6.3634 | 0.02641 | 2832.4 | 3096.5 | 6.2120 |
| 440 | 0.03742 | 2946.7 | 3246.1 | 6.5190 | 0.02911 | 2922.1 | 3213.2 | 6.3805 |
| 480 | 0.04034 | 3025.7 | 3348.4 | 6.6586 | 0.03160 | 3005.4 | 3321.4 | 6.5282 |
| 520 | 0.04313 | 3102.7 | 3447.7 | 6.7871 | 0.03394 | 3085.6 | 3425.1 | 6.6622 |
| 560 | 0.04582 | 3178.7 | 3545.3 | 6.9072 | 0.03619 | 3164.1 | 3526.0 | 6.7864 |
| 600 | 0.04845 | 3254.4 | 3642.0 | 7.0206 | 0.03837 | 3241.7 | 3625.3 | 6.9029 |
| 640 | 0.05102 | 3330.1 | 3738.3 | 7.1283 | 0.04048 | 3318.9 | 3723.7 | 7.0131 |
| 700 | 0.05481 | 3443.9 | 3882.4 | 7.2812 | 0.04358 | 3434.7 | 3870.5 | 7.1687 |
| 740 | 0.05729 | 3520.4 | 3978.7 | 7.3782 | 0.04560 | 3512.1 | 3968.1 | 7.2670 |
| | **$p$ = 120 bars = 12.0 MPa ($T_{sat}$ = 324.75°C)** | | | | **$p$ = 140 bars = 14.0 MPa ($T_{sat}$ = 336.75°C)** | | | |
| Sat. | 0.01426 | 2513.7 | 2684.9 | 5.4924 | 0.01149 | 2476.8 | 2637.6 | 5.3717 |
| 360 | 0.01811 | 2678.4 | 2895.7 | 5.8361 | 0.01422 | 2617.4 | 2816.5 | 5.6602 |
| 400 | 0.02108 | 2798.3 | 3051.3 | 6.0747 | 0.01722 | 2760.9 | 3001.9 | 5.9448 |
| 440 | 0.02355 | 2896.1 | 3178.7 | 6.2586 | 0.01954 | 2868.6 | 3142.2 | 6.1474 |
| 480 | 0.02576 | 2984.4 | 3293.5 | 6.4154 | 0.02157 | 2962.5 | 3264.5 | 6.3143 |
| 520 | 0.02781 | 3068.0 | 3401.8 | 6.5555 | 0.02343 | 3049.8 | 3377.8 | 6.4610 |
| 560 | 0.02977 | 3149.0 | 3506.2 | 6.6840 | 0.02517 | 3133.6 | 3486.0 | 6.5941 |
| 600 | 0.03164 | 3228.7 | 3608.3 | 6.8037 | 0.02683 | 3215.4 | 3591.1 | 6.7172 |
| 640 | 0.03345 | 3307.5 | 3709.0 | 6.9164 | 0.02843 | 3296.0 | 3694.1 | 6.8326 |
| 700 | 0.03610 | 3425.2 | 3858.4 | 7.0749 | 0.03075 | 3415.7 | 3846.2 | 6.9939 |
| 740 | 0.03781 | 3503.7 | 3957.4 | 7.1746 | 0.03225 | 3495.2 | 3946.7 | 7.0952 |

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**TABLE A.7 Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Acetylene (Ethyne)* | *Air [mixture]* | *Ammonia, anhyd.* | *Argon* |
|---|---|---|---|---|
| *Chemical formula* | $C_2H_2$ | | $NH_3$ | *Ar* |
| *Refrigerant number* | — | *729* | *717* | *740* |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 26.04 | 28.966 | 17.02 | 39.948 |
| Specific gravity, air = 1 | 0.90 | 1.00 | 0.59 | 1.38 |
| Specific volume, $ft^3/lb$ | 14.9 | 13.5 | 23.0 | 9.80 |
| Specific volume, $m^3/kg$ | 0.93 | 0.842 | 1.43 | 0.622 |
| Density of liquid (at atm bp), $lb/ft^3$ | 43.0 | 54.6 | 42.6 | 87.0 |
| Density of liquid (at atm bp), $kg/m^3$ | 693. | 879. | 686. | 1 400. |
| Vapor pressure at 25 deg C, psia | | | 145.4 | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | | 1.00 | |
| Viscosity (abs), lbm/ft·sec | $6.72 \times 10^{-6}$ | $12.1 \times 10^{-6}$ | $6.72 \times 10^{-6}$ | $13.4 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | 0.01 | 0.018 | 0.010 | 0.02 |
| Sound velocity in gas, m/sec | 343 | 346 | 415 | 322 |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.40 | 0.240 3 | 0.52 | 0.125 |
| Specific heat, $c_p$, J/kg·K | 1 674. | 1 005. | 2 175. | 523. |
| Specific heat ratio, $c_p/c_v$ | 1.25 | 1.40 | 1.3 | 1.67 |
| Gas constant $R$, ft-lb/lb·deg R | 59.3 | 53.3 | 90.8 | 38.7 |
| Gas constant $R$, J/kg·deg C | 319 | 286.8 | 488. | 208. |
| Thermal conductivity, Btu/hr·ft·deg F | 0.014 | 0.015 1 | 0.015 | 0.010 2 |
| Thermal conductivity, W/m·deg C | 0.024 | 0.026 | 0.026 | 0.017 2 |
| Boiling point (sat 14.7 psia), deg F | −103 | −320 | −28. | −303. |
| Boiling point (sat 760 mm), deg C | −75 | −195 | −33.3 | −186 |
| Latent heat of evap (at bp), Btu/lb | 264 | 88.2 | 589.3 | 70. |
| Latent heat of evap (at bp), J/kg | 614 000 | 205 000. | 1 373 000 | 163 000 |
| Freezing (melting) point, deg F (1 atm) | −116 | −357.2 | −107.9 | −308.5 |
| Freezing (melting) point, deg C (1 atm) | −82.2 | −216.2 | −77.7 | −189.2 |
| Latent heat of fusion, Btu/lb | 23. | 10.0 | 143.0 | |
| Latent heat of fusion, J/kg | 53 500 | 23 200 | 332 300 | |
| Critical temperature, deg F | 97.1 | −220.5 | 271.4 | −187.6 |
| Critical temperature, deg C | 36.2 | −140.3 | 132.5 | −122 |
| Critical pressure, psia | 907. | 550. | 1 650. | 707. |
| Critical pressure, $MN/m^2$ | 6.25 | 3.8 | 11.4 | 4.87 |
| Critical volume, $ft^3/lb$ | | 0.050 | 0.068 | 0.029 9 |
| Critical volume, $m^3/kg$ | | 0.003 | 0.004 24 | 0.001 86 |
| Flammable (yes or no) | Yes | No | No | No |
| Heat of combustion, $Btu/ft^3$ | 1 450 | — | — | — |
| Heat of combustion, Btu/lb | 21 600 | — | — | — |
| Heat of combustion, kJ/kg | 50 200 | — | — | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.

*Note:* The properties of pure gases are given at 25°C (77°F, 298 K) and atmospheric pressure (except as stated).

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Butadiene* | *n-Butane* | *Isobutane (2-Methyl propane)* | *1-Butene (Butylene)* |
|---|---|---|---|---|
| *Chemical formula* | $C_4H_6$ | $C_4H_{10}$ | $C_4H_{10}$ | $C_4H_8$ |
| *Refrigerant number* | — | *600* | *600a* | — |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 54.09 | 58.12 | 58.12 | 56.108 |
| Specific gravity, air = 1 | 1.87 | 2.07 | 2.07 | 1.94 |
| Specific volume, $ft^3/lb$ | 7.1 | 6.5 | 6.5 | 6.7 |
| Specific volume, $m^3/kg$ | 0.44 | 0.405 | 0.418 | 0.42 |
| Density of liquid (at atm bp), $lb/ft^3$ | | 37.5 | 37.2 | |
| Density of liquid (at atm bp), $kg/m^3$ | | 604. | 599. | |
| Vapor pressure at 25 deg C, psia | | 35.4 | 50.4 | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | 0.024 4 | 0.347 | |
| Viscosity (abs), lbm/ft·sec | | $4.8 \times 10^{-6}$ | | |
| Viscosity (abs), centipoises[a] | | 0.007 | | |
| Sound velocity in gas, m/sec | 226 | 216 | 216 | 222 |
| THERMAL AND THERMO-DYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.341 | 0.39 | 0.39 | 0.36 |
| Specific heat, $c_p$, J/kg·K | 1 427. | 1 675. | 1 630. | 1 505. |
| Specific heat ratio, $c_p/c_v$ | 1.12 | 1.096 | 1.10 | 1.112 |
| Gas constant $R$, ft-lb/lb·deg F | 28.55 | 26.56 | 26.56 | 27.52 |
| Gas constant $R$, J/kg·deg C | 154. | 143. | 143. | 148. |
| Thermal conductivity, Btu/hr·ft·deg F | | 0.01 | 0.01 | |
| Thermal conductivity, W/m·deg C | | 0.017 | 0.017 | |
| Boiling point (sat 14.7 psia), deg F | 24.1 | 31.2 | 10.8 | 20.6 |
| Boiling point (sat 760 mm), deg C | −4.5 | −0.4 | −11.8 | −6.3 |
| Latent heat of evap (at bp), Btu/lb | | 165.6 | 157.5 | 167.9 |
| Latent heat of evap (at bp), J/kg | | 386 000 | 366 000 | 391 000 |
| Freezing (melting) point, deg F (1 atm) | −164. | −217. | −229 | −301.6 |
| Freezing (melting) point, deg C (1 atm) | −109. | −138 | −145 | −185.3 |
| Latent heat of fusion, Btu/lb | | 19.2 | | 16.4 |
| Latent heat of fusion, J/kg | | 44 700 | | 38 100 |
| Critical temperature, deg F | | 306 | 273. | 291. |
| Critical temperature, deg C | 171. | 152. | 134. | 144. |
| Critical pressure, psia | 652. | 550. | 537. | 621. |
| Critical pressure, $MN/m^2$ | | 3.8 | 3.7 | 4.28 |
| Critical volume, $ft^3/lb$ | | 0.070 | | 0.068 |
| Critical volume, $m^3/kg$ | | 0.004 3 | | 0.004 2 |
| Flammable (yes or no) | Yes | Yes | Yes | Yes |
| Heat of combustion, $Btu/ft^3$ | 2 950 | 3 300 | 3 300 | 3 150 |
| Heat of combustion, Btu/lb | 20 900 | 21 400 | 21 400 | 21 000 |
| Heat of combustion, kJ/kg | 48 600 | 49 700 | 49 700 | 48 800 |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)*<br>*Chemical formula*<br>*Refrigerant number* | *cis-2-Butene*<br>$C_4H_8$<br>– | *trans-2-Butene*<br>$C_4H_8$<br>— | *Isobutene*<br>$C_4H_8$<br>— | *Carbon dioxide*<br>$CO_2$<br>*744* |
|---|---|---|---|---|
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 56.108 | 56.108 | 56.108 | 44.01 |
| Specific gravity, air = 1 | 1.94 | 1.94 | 1.94 | 1.52 |
| Specific volume, $ft^3/lb$ | 6.7 | 6.7 | 6.7 | 8.8 |
| Specific volume, $m^3/kg$ | 0.42 | 0.42 | 0.42 | 0.55 |
| Density of liquid (at atm bp), $lb/ft^3$ | | | | — |
| Density of liquid (at atm bp), $kg/m^3$ | | | | — |
| Vapor pressure at 25 deg C, psia | | | | 931. |
| Vapor pressure at 25 deg C, $MN/m^2$ | | | | 6.42 |
| Viscosity (abs), lbm/ft·sec | | | | $9.4 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | | | | 0.014 |
| Sound velocity in gas, m/sec | 223. | 221. | 221. | 270. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.327 | 0.365 | 0.37 | 0.205 |
| Specific heat, $c_p$, J/kg·K | 1 368. | 1 527. | 1 548. | 876. |
| Specific heat ratio, $c_p/c_v$ | 1.121 | 1.107 | 1.10 | 1.30 |
| Gas constant $R$, ft-lb/lb·deg F | | | | 35.1 |
| Gas constant $R$, J/kg·deg C | | | | 189. |
| Thermal conductivity, Btu/hr·ft·deg F | | | | 0.01 |
| Thermal conductivity, W/m·deg C | | | | 0.017 |
| Boiling point (sat 14.7 psia), deg F | 38.6 | 33.6 | 19.2 | −109.4[b] |
| Boiling point (sat 760 mm), deg C | 3.7 | 0.9 | −7.1 | −78.5 |
| Latent heat of evap (at bp), Btu/lb | 178.9 | 174.4 | 169. | 246. |
| Latent heat of evap (at bp), J/kg | 416 000. | 406 000. | 393 000. | 572 000. |
| Freezing (melting) point, deg F (1 atm) | −218. | −158. | | |
| Freezing (melting) point, deg C (1 atm) | −138.9 | −105.5 | | |
| Latent heat of fusion, Btu/lb | 31.2 | 41.6 | 25.3 | — |
| Latent heat of fusion, J/kg | 72 600. | 96 800. | 58 800. | — |
| Critical temperature, deg F | | | | 88. |
| Critical temperature, deg C | 160. | 155. | | 31. |
| Critical pressure, psia | 595. | 610. | | 1 072. |
| Critical pressure, $MN/m^2$ | 4.10 | 4.20 | | 7.4 |
| Critical volume, $ft^3/lb$ | | | | |
| Critical volume, $m^3/kg$ | | | | |
| Flammable (yes or no) | Yes | Yes | Yes | No |
| Heat of combustion, $Btu/ft^3$ | 3 150. | 3 150. | 3 150. | — |
| Heat of combustion, Btu/lb | 21 000. | 21 000. | 21 000. | — |
| Heat of combustion, kJ/kg | 48 800. | 48 800. | 48 800. | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.
[b]Sublimes.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Carbon monoxide* | *Chlorine* | *Deuterium* | *Ethane* |
|---|---|---|---|---|
| *Chemical formula* | $CO$ | $Cl_2$ | $D_2$ | $C_2H_6$ |
| *Refrigerant number* | — | — | — | *170* |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 28.011 | 70.906 | 2.014 | 30.070 |
| Specific gravity, air = 1 | 0.967 | 2.45 | 0.070 | 1.04 |
| Specific volume, $ft^3/lb$ | 14.0 | 5.52 | 194.5 | 13.025 |
| Specific volume, $m^3/kg$ | 0.874 | 0.344 | 12.12 | 0.815 |
| Density of liquid (at atm bp), $lb/ft^3$ | | 97.3 | | 28. |
| Density of liquid (at atm bp), $kg/m^3$ | | 1 559. | | 449. |
| Vapor pressure at 25 deg C, psia | | | 0.756 | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | | 0.005 2 | |
| Viscosity (abs), lbm/ft·sec | $12.1 \times 10^{-6}$ | $9.4 \times 10^{-6}$ | $8.75 \times 10^{-6}$ | $64. \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | 0.018 | 0.014 | 0.013 | 0.095 |
| Sound velocity in gas, m/sec | 352. | 215. | 930. | 316. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.25 | 0.114 | 1.73 | 0.41 |
| Specific heat, $c_p$, J/kg·K | 1 046. | 477. | 7 238. | 1 715. |
| Specific heat ratio, $c_p/c_v$ | 1.40 | 1.35 | 1.40 | 1.20 |
| Gas constant $R$, ft-lb/lb·deg F | 55.2 | 21.8 | 384. | 51.4 |
| Gas constant $R$, J/kg·deg C | 297. | 117. | 2 066. | 276. |
| Thermal conductivity, Btu/hr·ft·deg F | 0.014 | 0.005 | 0.081 | 0.010 |
| Thermal conductivity, W/m·deg C | 0.024 | 0.008 7 | 0.140 | 0.017 |
| Boiling point (sat 14.7 psia), deg F | −312.7 | −29.2 | | −127. |
| Boiling point (sat 760 mm), deg C | −191.5 | −34. | | −88.3 |
| Latent heat of evap (at bp), Btu/lb | 92.8 | 123.7 | | 210. |
| Latent heat of evap (at bp), J/kg | 216 000. | 288 000. | | 488 000. |
| Freezing (melting) point, deg F (1 atm) | −337. | −150. | | −278. |
| Freezing (melting) point, deg C (1 atm) | −205. | −101. | | −172.2 |
| Latent heat of fusion, Btu/lb | 12.8 | 41.0 | | 41. |
| Latent heat of fusion, J/kg | | 95 400. | | 95 300. |
| Critical temperature, deg F | −220. | 291. | −390.6 | 90.1 |
| Critical temperature, deg C | −140. | 144. | −234.8 | 32.2 |
| Critical pressure, psia | 507. | 1 120. | 241. | 709. |
| Critical pressure, $MN/m^2$ | 3.49 | 7.72 | 1.66 | 4.89 |
| Critical volume, $ft^3/lb$ | 0.053 | 0.028 | 0.239 | 0.076 |
| Critical volume, $m^3/kg$ | 0.003 3 | 0.001 75 | 0.014 9 | 0.004 7 |
| Flammable (yes or no) | Yes | No | | Yes |
| Heat of combustion, $Btu/ft^3$ | 310. | — | | |
| Heat of combustion, Btu/lb | 4 340. | — | | 22 300. |
| Heat of combustion, kJ/kg | 10 100. | — | | 51 800. |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Ethyl chloride* | *Ethylene (Ethene)* | *Fluorine* |
|---|---|---|---|
| *Chemical formula* | $C_2H_5Cl$ | $C_2H_4$ | $F_2$ |
| *Refrigerant number* | *160* | *1150* | |
| CHEMICAL AND PHYSICAL PROPERTIES | | | |
| Molecular weight | 64.515 | 28.054 | 37.996 |
| Specific gravity, air = 1 | 2.23 | 0.969 | 1.31 |
| Specific volume, $ft^3/lb$ | 6.07 | 13.9 | 10.31 |
| Specific volume, $m^3/kg$ | 0.378 | 0.87 | 0.706 |
| Density of liquid (at atm bp), $lb/ft^3$ | 56.5 | 35.5 | |
| Density of liquid (at atm bp), $kg/m^3$ | 905. | 569. | |
| Vapor pressure at 25 deg C, psia | | | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | | |
| Viscosity (abs), lbm/ft·sec | | $6.72 \times 10^{-6}$ | $16.1 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | | 0.010 | 0.024 |
| Sound velocity in gas, m/sec | 204. | 331. | 290. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.27 | 0.37 | 0.198 |
| Specific heat, $c_p$, J/kg·K | 1 130. | 1 548. | 828. |
| Specific heat ratio, $c_p/c_v$ | 1.13 | 1.24 | 1.35 |
| Gas constant $R$, ft-lb/lb·deg F | 24.0 | 55.1 | 40.7 |
| Gas constant $R$, J/kg·deg C | 129. | 296. | 219. |
| Thermal conductivity, Btu/hr·ft·deg F | | 0.010 | 0.016 |
| Thermal conductivity, W/m·deg C | | 0.017 | 0.028 |
| Boiling point (sat 14.7 psia), deg F | 54. | −155. | −306.4 |
| Boiling point (sat 760 mm), deg C | 12.2 | −103.8 | −188. |
| Latent heat of evap (at bp), Btu/lb | 166. | 208. | 74. |
| Latent heat of evap (at bp), J/kg | 386 000. | 484 000. | 172 000. |
| Freezing (melting) point, deg F (1 atm) | −218. | −272. | −364. |
| Freezing (melting) point, deg C (1 atm) | −138.9 | −169. | −220. |
| Latent heat of fusion, Btu/lb | 29.3 | 51.5 | 11. |
| Latent heat of fusion, J/kg | 68 100. | 120 000. | 25 600. |
| Critical temperature, deg F | 368.6 | 49. | −200 |
| Critical temperature, deg C | 187. | 9.5 | −129. |
| Critical pressure, psia | 764. | 741. | 810. |
| Critical pressure, $MN/m^2$ | 5.27 | 5.11 | 5.58 |
| Critical volume, $ft^3/lb$ | 0.049 | 0.073 | |
| Critical volume, $m^3/kg$ | 0.003 06 | 0.004 6 | |
| Flammable (yes or no) | No | Yes | |
| Heat of combustion, $Btu/ft^3$ | — | 1 480. | |
| Heat of combustion, Btu/lb | — | 20 600. | |
| Heat of combustion, kJ/kg | — | 47 800. | |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Fluorocarbons* | | | |
|---|---|---|---|---|
| *Chemical formula* | $CCl_3F$ | $CCl_2F_2$ | $CClF_3$ | $CBrF_3$ |
| *Refrigerant number* | *11* | *12* | *13* | *13B1* |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 137.37 | 120.91 | 104.46 | 148.91 |
| Specific gravity, air = 1 | 4.74 | 4.17 | 3.61 | 5.14 |
| Specific volume, $ft^3/lb$ | 2.74 | 3.12 | 3.58 | 2.50 |
| Specific volume, $m^3/kg$ | 0.171 | 0.195 | 0.224 | 0.975 |
| Density of liquid (at atm bp), $lb/ft^3$ | 92.1 | 93.0 | 95.0 | 124.4 |
| Density of liquid (at atm bp), $kg/m^3$ | 1 475. | 1 490. | 1 522. | 1 993. |
| Vapor pressure at 25 deg C, psia | | 94.51 | 516. | 234.8 |
| Vapor pressure at 25 deg C, $MN/m^2$ | | 0.652 | 3.56 | 1.619 |
| Viscosity (abs), lbm/ft·sec | $7.39 \times 10^{-6}$ | $8.74 \times 10^{-6}$ | | |
| Viscosity (abs), centipoises[a] | 0.011 | 0.013 | | |
| Sound velocity in gas, m/sec | | | | |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.14 | 0.146 | 0.154 | |
| Specific heat, $c_p$, J/kg·K | 586. | 611. | 644. | |
| Specific heat ratio, $c_p/c_v$ | 1.14 | 1.14 | 1.145 | |
| Gas constant $R$, ft-lb/lb·deg F | | | | |
| Gas constant $R$, J/kg·deg C | | | | |
| Thermal conductivity, Btu/hr·ft·deg F | 0.005 | 0.006 | | |
| Thermal conductivity, W/m·deg C | 0.008 7 | 0.010 4 | | |
| Boiling point (sat 14.7 psia), deg F | 74.9 | −21.8 | −114.6 | −72. |
| Boiling point (sat 760 mm), deg C | 23.8 | −29.9 | −81.4 | −57.8 |
| Latent heat of evap (at bp), Btu/lb | 77.5 | 71.1 | 63.0 | 51.1 |
| Latent heat of evap (at bp), J/kg | 180 000. | 165 000. | 147 000. | 119 000. |
| Freezing (melting) point, deg F (1 atm) | −168. | −252. | −294. | −270. |
| Freezing (melting) point, deg C (1 atm) | −111. | −157.8 | −181.1 | −167.8 |
| Latent heat of fusion, Btu/lb | | | | |
| Latent heat of fusion, J/kg | | | | |
| Critical temperature, deg F | 388.4 | 233. | 83.9 | 152. |
| Critical temperature, deg C | 198. | 111.7 | 28.8 | 66.7 |
| Critical pressure, psia | 635. | 582. | 559. | 573. |
| Critical pressure, $MN/m^2$ | 4.38 | 4.01 | 3.85 | 3.95 |
| Critical volume, $ft^3/lb$ | 0.028 9 | 0.287 | 0.027 7 | 0.021 5 |
| Critical volume, $m^3/kg$ | 0.001 80 | 0.018 | 0.001 73 | 0.001 34 |
| Flammable (yes or no) | No | No | No | No |
| Heat of combustion, $Btu/ft^3$ | — | — | — | — |
| Heat of combustion, Btu/lb | — | — | — | — |
| Heat of combustion, kJ/kg | — | — | — | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Fluorocarbons* | | | |
|---|---|---|---|---|
| *Chemical formula* | $CF_4$ | $CHCl_2F$ | $CHClF_2$ | $C_2Cl_2F_4$ |
| *Refrigerant number* | *14* | *21* | *22* | *114* |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 88.00 | 102.92 | 86.468 | 170.92 |
| Specific gravity, air = 1 | 3.04 | 3.55 | 2.99 | 5.90 |
| Specific volume, $ft^3/lb$ | 4.34 | 3.7 | 4.35 | 2.6 |
| Specific volume, $m^3/kg$ | 0.271 | 0.231 | 0.271 | 0.162 |
| Density of liquid (at atm bp), $lb/ft^3$ | 102.0 | 87.7 | 88.2 | 94.8 |
| Density of liquid (at atm bp), $kg/m^3$ | 1 634. | 1 405. | 1 413. | 1 519. |
| Vapor pressure at 25 deg C, psia | | 26.4 | 151.4 | 30.9 |
| Vapor pressure at 25 deg C, $MN/m^2$ | | 0.182 | 1.044 | 0.213 |
| Viscosity (abs), lbm/ft·sec | | $8.06 \times 10^{-6}$ | $8.74 \times 10^{-6}$ | $8.06 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | | 0.012 | 0.013 | 0.012 |
| Sound velocity in gas, m/sec | | | | |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | | 0.139 | 0.157 | 0.158 |
| Specific heat, $c_p$, J/kg·K | | 582. | 657. | 661. |
| Specific heat ratio, $c_p/c_v$ | | 1.18 | 1.185 | 1.09 |
| Gas constant $R$, ft-lb/lb·deg F | | | | |
| Gas constant $R$, J/kg·deg C | | | | |
| Thermal conductivity, Btu/hr·ft·deg F | | | 0.007 | 0.006 |
| Thermal conductivity, W/m·deg C | | | 0.012 | 0.010 |
| Boiling point (sat 14.7 psia), deg F | −198.2 | 48.1 | −41.3 | 38.4 |
| Boiling point (sat 760 mm), deg C | −127.9 | 9.0 | −40.7 | 3.55 |
| Latent heat of evap (at bp), Btu/lb | 58.5 | 104.1 | 100.4 | 58.4 |
| Latent heat of evap (at bp), J/kg | 136 000. | 242 000. | 234 000. | 136 000. |
| Freezing (melting) point, deg F (1 atm) | −299. | −211. | −256. | −137. |
| Freezing (melting) point, deg C (1 atm) | −183.8 | −135. | −160. | −93.8 |
| Latent heat of fusion, Btu/lb | 2.53 | | | |
| Latent heat of fusion, J/kg | 5 880. | | | |
| Critical temperature, deg F | −49.9 | 353.3 | 204.8 | 294. |
| Critical temperature, deg C | −45.5 | 178.5 | 96.5 | |
| Critical pressure, psia | 610. | 750. | 715. | 475. |
| Critical pressure, $MN/m^2$ | 4.21 | 5.17 | 4.93 | 3.28 |
| Critical volume, $ft^3/lb$ | 0.025 | 0.030 7 | 0.030 5 | 0.027 5 |
| Critical volume, $m^3/kg$ | 0.001 6 | 0.001 91 | 0.001 90 | 0.001 71 |
| Flammable (yes or no) | No | No | No | No |
| Heat of combustion, $Btu/ft^3$ | — | — | — | — |
| Heat of combustion, Btu/lb | — | — | — | — |
| Heat of combustion, kJ/kg | — | — | — | — |

[a]For N·sec/$m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Fluorocarbons* | | | *Helium* |
|---|---|---|---|---|
| *Chemical formula* | $C_2ClF_5$ | $C_2H_3ClF_2$ | $C_2H_4F_2$ | *He* |
| *Refrigerant number* | *115* | *142b* | *152a* | *704* |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 154.47 | 100.50 | 66.05 | 4.002 6 |
| Specific gravity, air = 1 | 5.33 | 3.47 | 2.28 | 0.138 |
| Specific volume, $ft^3/lb$ | 2.44 | 3.7 | 5.9 | 97.86 |
| Specific volume, $m^3/kg$ | 0.152 | 0.231 | 0.368 | 6.11 |
| Density of liquid (at atm bp), $lb/ft^3$ | 96.5 | 74.6 | 62.8 | 7.80 |
| Density of liquid (at atm bp), $kg/m^3$ | 1 546. | 1 195. | 1 006. | 125. |
| Vapor pressure at 25 deg C, psia | 132.1 | 49.1 | 86.8 | |
| Vapor pressure at 25 deg C, $MN/m^2$ | 0.911 | 0.338 5 | 0.596 | |
| Viscosity (abs), lbm/ft·sec | | | | $13.4 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | | | | 0.02 |
| Sound velocity in gas, m/sec | | | | 1 015. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.161 | | | 1.24 |
| Specific heat, $c_p$, J/kg·K | 674. | | | 5 188. |
| Specific heat ratio, $c_p/c_v$ | 1.091 | | | 1.66 |
| Gas constant $R$, ft-lb/lb·deg F | | | | 386. |
| Gas constant $R$, J/kg·deg C | | | | 2 077. |
| Thermal conductivity, Btu/hr·ft·deg F | | | | 0.086 |
| Thermal conductivity, W/m·deg C | | | | 0.149 |
| Boiling point (sat 14.7 psia), deg F | −38.0 | 14. | −13. | −452. |
| Boiling point (sat 760 mm), deg C | −38.9 | −10.0 | −25.0 | 4.22 K |
| Latent heat of evap (at bp), Btu/lb | 53.4 | 92.5 | 137.1 | 10.0 |
| Latent heat of evap (at bp), J/kg | 124 000. | 215 000. | 319 000. | 23 300. |
| Freezing (melting) point, deg F (1 atm) | −149. | | | [b] |
| Freezing (melting) point, deg C (1 atm) | −100.6 | | | — |
| Latent heat of fusion, Btu/lb | | | | — |
| Latent heat of fusion, J/kg | | | | — |
| Critical temperature, deg F | 176. | | 387. | −450.3 |
| Critical temperature, deg C | | | | 5.2 K |
| Critical pressure, psia | 457.6 | | | 33.22 |
| Critical pressure, $MN/m^2$ | 3.155 | | | |
| Critical volume, $ft^3/lb$ | 0.026 1 | | | 0.231 |
| Critical volume, $m^3/kg$ | 0.001 63 | | | 0.014 4 |
| Flammable (yes or no) | No | No | No | No |
| Heat of combustion, $Btu/ft^3$ | — | — | — | — |
| Heat of combustion, Btu/lb | — | — | — | — |
| Heat of combustion, kJ/kg | — | — | — | — |

[a]For N·sec/$m^2$ divide by 1 000.
[b]Helium cannot be solidified at atmospheric pressure.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Hydrogen* | *Hydrogen chloride* | *Hydrogen sulfide* | *Krypton* |
|---|---|---|---|---|
| *Chemical formula* | $H_2$ | $HCl$ | $H_2S$ | $Kr$ |
| *Refrigerant number* | *702* | — | — | — |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 2.016 | 36.461 | 34.076 | 83.80 |
| Specific gravity, air = 1 | 0.070 | 1.26 | 1.18 | 2.89 |
| Specific volume, $ft^3/lb$ | 194. | 10.74 | 11.5 | 4.67 |
| Specific volume, $m^3/kg$ | 12.1 | 0.670 | 0.093 0 | 0.291 |
| Density of liquid (at atm bp), $lb/ft^3$ | 4.43 | 74.4 | 62. | 150.6 |
| Density of liquid (at atm bp), $kg/m^3$ | 71.0 | 1 192. | 993. | 2 413. |
| Vapor pressure at 25 deg C, psia | | | | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | | | |
| Viscosity (abs), lbm/ft·sec | $6.05 \times 10^{-6}$ | $10.1 \times 10^{-6}$ | $8.74 \times 10^{-6}$ | $16.8 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | 0.009 | 0.015 | 0.013 | 0.025 |
| Sound velocity in gas, m/sec | 1 315. | 310. | 302. | 223. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 3.42 | 0.194 | 0.23 | 0.059 |
| Specific heat, $c_p$, J/kg·K | 14 310. | 812. | 962. | 247. |
| Specific heat ratio, $c_p/c_v$ | 1.405 | 1.39 | 1.33 | 1.68 |
| Gas constant $R$, ft-lb/lb·deg F | 767. | 42.4 | 45.3 | 18.4 |
| Gas constant $R$, J/kg·deg C | 4 126. | 228. | 244. | 99.0 |
| Thermal conductivity, Btu/hr·ft·deg F | 0.105 | 0.008 | 0.008 | 0.005 4 |
| Thermal conductivity, W/m·deg C | 0.018 2 | 0.014 | 0.014 | 0.009 3 |
| Boiling point (sat 14.7 psia), deg F | −423. | −121. | −76. | −244. |
| Boiling point (sat 760 mm), deg C | 20.4 K | −85. | −60. | −153. |
| Latent heat of evap (at bp), Btu/lb | 192. | 190.5 | 234. | 46.4 |
| Latent heat of evap (at bp), J/kg | 447 000. | 443 000. | 544 000. | 108 000. |
| Freezing (melting) point, deg F (1 atm) | −434.6 | −169.6 | −119.2 | −272. |
| Freezing (melting) point, deg C (1 atm) | −259.1 | −112. | −84. | −169. |
| Latent heat of fusion, Btu/lb | 25.0 | 23.4 | 30.2 | 4.7 |
| Latent heat of fusion, J/kg | 58 000. | 54 400. | 70 200. | 10 900. |
| Critical temperature, deg F | −399.8 | 124. | 213. | |
| Critical temperature, deg C | −240.0 | 51.2 | 100.4 | −63.8 |
| Critical pressure, psia | 189. | 1 201. | 1 309. | 800. |
| Critical pressure, $MN/m^2$ | 1.30 | 8.28 | 9.02 | 5.52 |
| Critical volume, $ft^3/lb$ | 0.53 | 0.038 | 0.046 | 0.017 7 |
| Critical volume, $m^3/kg$ | 0.033 | 0.002 4 | 0.002 9 | 0.001 1 |
| Flammable (yes or no) | Yes | No | Yes | No |
| Heat of combustion, $Btu/ft^3$ | 320. | — | 700. | — |
| Heat of combustion, Btu/lb | 62 050. | — | 8 000. | — |
| Heat of combustion, kJ/kg | 144 000. | — | 18 600. | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Methane* | *Methyl chloride* | *Neon* | *Nitric oxide* |
|---|---|---|---|---|
| *Chemical formula* | $CH_4$ | $CH_3Cl$ | *Ne* | *NO* |
| *Refrigerant number* | *50* | *40* | *720* | — |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 16.044 | 50.488 | 20.179 | 30.006 |
| Specific gravity, air = 1 | 0.554 | 1.74 | 0.697 | 1.04 |
| Specific volume, $ft^3/lb$ | 24.2 | 7.4 | 19.41 | 13.05 |
| Specific volume, $m^3/kg$ | 1.51 | 0.462 | 1.211 | 0.814 |
| Density of liquid (at atm bp), $lb/ft^3$ | 26.3 | 62.7 | 75.35 | |
| Density of liquid (at atm bp), $kg/m^3$ | 421. | 1 004. | 1 207. | |
| Vapor pressure at 25 deg C, psia | | 82.2 | | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | 0.567 | | |
| Viscosity (abs), lbm/ft·sec | $7.39 \times 10^{-6}$ | $7.39 \times 10^{-6}$ | $21.5 \times 10^{-6}$ | $12.8 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | 0.011 | 0.011 | 0.032 | 0.019 |
| Sound velocity in gas, m/sec | 446. | 251. | 454. | 341. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.54 | 0.20 | 0.246 | 0.235 |
| Specific heat, $c_p$, J/kg·K | 2 260. | 837. | 1 030. | 983. |
| Specific heat ratio, $c_p/c_v$ | 1.31 | 1.28 | 1.64 | 1.40 |
| Gas constant $R$, ft-lb/lb·deg F | 96. | 30.6 | 76.6 | 51.5 |
| Gas constant $R$, J/kg·deg C | 518. | 165. | 412. | 277. |
| Thermal conductivity, Btu/hr·ft·deg F | 0.02 | 0.006 | 0.028 | 0.015 |
| Thermal conductivity, W/m·deg C | 0.035 | 0.010 | 0.048 | 0.026 |
| Boiling point (sat 14.7 psia), deg F | −259. | −10.7 | −410.9 | −240. |
| Boiling point (sat 760 mm), deg C | −434.2 | −23.7 | −246. | −151.5 |
| Latent heat of evap (at bp), Btu/lb | 219.2 | 184.1 | 37. | |
| Latent heat of evap (at bp), J/kg | 510 000. | 428 000. | 86 100. | |
| Freezing (melting) point, deg F (1 atm) | −296.6 | −144. | −415.6 | −258. |
| Freezing (melting) point, deg C (1 atm) | −182.6 | −97.8 | −248.7 | −161. |
| Latent heat of fusion, Btu/lb | 14. | 56. | 6.8 | 32.9 |
| Latent heat of fusion, J/kg | 32 600. | 130 000. | 15 800. | 76 500. |
| Critical temperature, deg F | −116. | 289.4 | −379.8 | −136. |
| Critical temperature, deg C | −82.3 | 143. | −228.8 | −93.3 |
| Critical pressure, psia | 673. | 968. | 396. | 945. |
| Critical pressure, $MN/m^2$ | 4.64 | 6.67 | 2.73 | 6.52 |
| Critical volume, $ft^3/lb$ | 0.099 | 0.043 | 0.033 | 0.033 2 |
| Critical volume, $m^3/kg$ | 0.006 2 | 0.002 7 | 0.002 0 | 0.002 07 |
| Flammable (yes or no) | Yes | Yes | No | No |
| Heat of combustion, $Btu/ft^3$ | 985. | | | — |
| Heat of combustion, Btu/lb | 2 290. | | — | — |
| Heat of combustion, kJ/kg | | | — | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Nitrogen* | *Nitrous oxide* | *Oxygen* | *Ozone* |
|---|---|---|---|---|
| *Chemical formula* | $N_2$ | $N_2O$ | $O_2$ | $O_3$ |
| *Refrigerant number* | *728* | *744A* | *732* | — |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 28.013 4 | 44.012 | 31.998 8 | 47.998 |
| Specific gravity, air = 1 | 0.967 | 1.52 | 1.105 | 1.66 |
| Specific volume, $ft^3/lb$ | 13.98 | 8.90 | 12.24 | 8.16 |
| Specific volume, $m^3/kg$ | 0.872 | 0.555 | 0.764 | 0.509 |
| Density of liquid (at atm bp), $lb/ft^3$ | 50.46 | 76.6 | 71.27 | |
| Density of liquid (at atm bp), $kg/m^3$ | 808.4 | 1 227. | 1 142. | |
| Vapor pressure at 25 deg C, psia | | | | |
| Vapor pressure at 25 deg C, $MN/m^2$ | | | | |
| Viscosity (abs), lbm/ft·sec | $12.1 \times 10^{-6}$ | $10.1 \times 10^{-6}$ | $13.4 \times 10^{-6}$ | $8.74 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | 0.018 | 0.015 | 0.020 | 0.013 |
| Sound velocity in gas, m/sec | 353. | 268. | 329. | |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.249 | 0.21 | 0.220 | 0.196 |
| Specific heat, $c_p$, J/kg·K | 1 040. | 879. | 920. | 820. |
| Specific heat ratio, $c_p/c_v$ | 1.40 | 1.31 | 1.40 | |
| Gas constant $R$, ft-lb/lb·deg F | 55.2 | 35.1 | 48.3 | 32.2 |
| Gas constant $R$, J/kg·deg C | 297. | 189. | 260. | 173. |
| Thermal conductivity, Btu/hr·ft·deg F | 0.015 | 0.010 | 0.015 | 0.019 |
| Thermal conductivity, W/m·deg C | 0.026 | 0.017 | 0.026 | 0.033 |
| Boiling point (sat 14.7 psia), deg F | −320.4 | −127.3 | −297.3 | −170. |
| Boiling point (sat 760 mm), deg C | −195.8 | −88.5 | −182.97 | −112. |
| Latent heat of evap (at bp), Btu/lb | 85.5 | 161.8 | 91.7 | |
| Latent heat of evap (at bp), J/kg | 199 000. | 376 000. | 213 000. | |
| Freezing (melting) point, deg F (1 atm) | −346. | −131.5 | −361.1 | −315.5 |
| Freezing (melting) point, deg C (1 atm) | −210. | −90.8 | −218.4 | −193. |
| Latent heat of fusion, Btu/lb | 11.1 | 63.9 | 5.9 | 97.2 |
| Latent heat of fusion, J/kg | 25 800. | 149 000. | 13 700. | 226 000. |
| Critical temperature, deg F | −232.6 | 97.7 | −181.5 | 16. |
| Critical temperature, deg C | −147. | 36.5 | −118.6 | −9. |
| Critical pressure, psia | 493. | 1 052. | 726. | 800. |
| Critical pressure, $MN/m^2$ | 3.40 | 7.25 | 5.01 | 5.52 |
| Critical volume, $ft^3/lb$ | 0.051 | 0.036 | 0.040 | 0.029 8 |
| Critical volume, $m^3/kg$ | 0.003 18 | 0.002 2 | 0.002 5 | 0.001 86 |
| Flammable (yes or no) | No | No | No | No |
| Heat of combustion, $Btu/ft^3$ | — | — | — | — |
| Heat of combustion, Btu/lb | — | — | — | — |
| Heat of combustion, kJ/kg | — | — | — | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.7 (continued) Chemical, Physical, and Thermal Properties of Gases: Gases and Vapors, Including Fuels and Refrigerants, English and Metric Units**

| *Common name(s)* | *Propane* | *Propylene (Propene)* | *Sulfur dioxide* | *Xenon* |
|---|---|---|---|---|
| *Chemical formula* | $C_3H_8$ | $C_3H_6$ | $SO_2$ | *Xe* |
| *Refrigerant number* | *290* | *1 270* | *764* | — |
| CHEMICAL AND PHYSICAL PROPERTIES | | | | |
| Molecular weight | 44.097 | 42.08 | 64.06 | 131.30 |
| Specific gravity, air = 1 | 1.52 | 1.45 | 2.21 | 4.53 |
| Specific volume, $ft^3/lb$ | 8.84 | 9.3 | 6.11 | 2.98 |
| Specific volume, $m^3/kg$ | 0.552 | 0.58 | | |
| Density of liquid (at atm bp), $lb/ft^3$ | 36.2 | 37.5 | 42.8 | 190.8 |
| Density of liquid (at atm bp), $kg/m^3$ | 580. | 601. | 585. | 3 060. |
| Vapor pressure at 25 deg C, psia | 135.7 | 166.4 | 56.6 | |
| Vapor pressure at 25 deg C, $MN/m^2$ | 0.936 | 1.147 | 0.390 | |
| Viscosity (abs), lbm/ft·sec | $53.8 \times 10^{-6}$ | $57.1 \times 10^{-6}$ | $8.74 \times 10^{-6}$ | $15.5 \times 10^{-6}$ |
| Viscosity (abs), centipoises[a] | 0.080 | 0.085 | 0.013 | 0.023 |
| Sound velocity in gas, m/sec | 253. | 261. | 220. | 177. |
| THERMAL AND THERMODYNAMIC PROPERTIES | | | | |
| Specific heat, $c_p$, Btu/lb·deg F or cal/g·deg C | 0.39 | 0.36 | 0.11 | 0.115 |
| Specific heat, $c_p$, J/kg·K | 1 630. | 1 506. | 460. | 481. |
| Specific heat ratio, $c_p/c_v$ | 1.2 | 1.16 | 1.29 | 1.67 |
| Gas constant $R$, ft-lb/lb·deg F | 35.0 | 36.7 | 24.1 | 11.8 |
| Gas constant $R$, J/kg·deg C | 188. | 197. | 130. | 63.5 |
| Thermal conductivity, Btu/hr·ft·deg F | 0.010 | 0.010 | 0.006 | 0.003 |
| Thermal conductivity, W/m·deg C | 0.017 | 0.017 | 0.010 | 0.005 2 |
| Boiling point (sat 14.7 psia), deg F | −44. | −54. | 14.0 | −162.5 |
| Boiling point (sat 760 mm), deg C | −42.2 | −48.3 | −10. | −108. |
| Latent heat of evap (at bp), Btu/lb | 184. | 188.2 | 155.5 | 41.4 |
| Latent heat of evap (at bp), J/kg | 428 000. | 438 000. | 362 000. | 96 000. |
| Freezing (melting) point, deg F (1 atm) | −309.8 | −301. | −104. | −220. |
| Freezing (melting) point, deg C (1 atm) | −189.9 | −185. | −75.5 | −140. |
| Latent heat of fusion, Btu/lb | 19.1 | | 58.0 | 10. |
| Latent heat of fusion, J/kg | 44 400. | | 135 000. | 23 300. |
| Critical temperature, deg F | 205. | 197. | 315.5 | 61.9 |
| Critical temperature, deg C | 96. | 91.7 | 157.6 | 16.6 |
| Critical pressure, psia | 618. | 668. | 1 141. | 852. |
| Critical pressure, $MN/m^2$ | 4.26 | 4.61 | 7.87 | 5.87 |
| Critical volume, $ft^3/lb$ | 0.073 | 0.069 | 0.03 | 0.014 5 |
| Critical volume, $m^3/kg$ | 0.004 5 | 0.004 3 | 0.001 9 | 0.000 90 |
| Flammable (yes or no) | Yes | Yes | No | No |
| Heat of combustion, $Btu/ft^3$ | 2 450. | 2 310. | — | — |
| Heat of combustion, Btu/lb | 21 660. | 21 500. | — | — |
| Heat of combustion, kJ/kg | 50 340. | 50 000. | — | — |

[a]For $N \cdot sec/m^2$ divide by 1 000.

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**TABLE A.8 Ideal Gas Properties of Air**

## Part a. SI Units

**$T$(K), $h$ and $u$(kJ/kg), $s^\circ$(kJ/kg·K)**

| $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^\circ$ | $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^\circ$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 199.97 | 0.3363 | 142.56 | 1707. | 1.29559 | 450 | 451.80 | 5.775 | 322.62 | 223.6 | 2.11161 |
| 210 | 209.97 | 0.3987 | 149.69 | 1512. | 1.34444 | 460 | 462.02 | 6.245 | 329.97 | 211.4 | 2.13407 |
| 220 | 219.97 | 0.4690 | 156.82 | 1346. | 1.39105 | 470 | 472.24 | 6.742 | 337.32 | 200.1 | 2.15604 |
| 230 | 230.02 | 0.5477 | 164.00 | 1205. | 1.43557 | 480 | 482.49 | 7.268 | 344.70 | 189.5 | 2.17760 |
| 240 | 240.02 | 0.6355 | 171.13 | 1084. | 1.47824 | 490 | 492.74 | 7.824 | 352.08 | 179.7 | 2.19876 |
| 250 | 250.05 | 0.7329 | 178.28 | 979. | 1.51917 | 500 | 503.02 | 8.411 | 359.49 | 170.6 | 2.21952 |
| 260 | 260.09 | 0.8405 | 185.45 | 887.8 | 1.55848 | 510 | 513.32 | 9.031 | 366.92 | 162.1 | 2.23993 |
| 270 | 270.11 | 0.9590 | 192.60 | 808.0 | 1.59634 | 520 | 523.63 | 9.684 | 374.36 | 154.1 | 2.25997 |
| 280 | 280.13 | 1.0889 | 199.75 | 738.0 | 1.63279 | 530 | 533.98 | 10.37 | 381.84 | 146.7 | 2.27967 |
| 285 | 285.14 | 1.1584 | 203.33 | 706.1 | 1.65055 | 540 | 544.35 | 11.10 | 389.34 | 139.7 | 2.29906 |
| 290 | 290.16 | 1.2311 | 206.91 | 676.1 | 1.66802 | 550 | 554.74 | 11.86 | 396.86 | 133.1 | 2.31809 |
| 295 | 295.17 | 1.3068 | 210.49 | 647.9 | 1.68515 | 560 | 565.17 | 12.66 | 404.42 | 127.0 | 2.33685 |
| 300 | 300.19 | 1.3860 | 214.07 | 621.2 | 1.70203 | 570 | 575.59 | 13.50 | 411.97 | 121.2 | 2.35531 |
| 305 | 305.22 | 1.4686 | 217.67 | 596.0 | 1.71865 | 580 | 586.04 | 14.38 | 419.55 | 115.7 | 2.37348 |
| 310 | 310.24 | 1.5546 | 221.25 | 572.3 | 1.73498 | 590 | 596.52 | 15.31 | 427.15 | 110.6 | 2.39140 |
| 315 | 315.27 | 1.6442 | 224.85 | 549.8 | 1.75106 | 600 | 607.02 | 16.28 | 434.78 | 105.8 | 2.40902 |
| 320 | 320.29 | 1.7375 | 228.42 | 528.6 | 1.76690 | 610 | 617.53 | 17.30 | 442.42 | 101.2 | 2.42644 |
| 325 | 325.31 | 1.8345 | 232.02 | 508.4 | 1.78249 | 620 | 628.07 | 18.36 | 450.09 | 96.92 | 2.44356 |
| 330 | 330.34 | 1.9352 | 235.61 | 489.4 | 1.79783 | 630 | 638.63 | 19.84 | 457.78 | 92.84 | 2.46048 |
| 340 | 340.42 | 2.149 | 242.82 | 454.1 | 1.82790 | 640 | 649.22 | 20.64 | 465.50 | 88.99 | 2.47716 |
| 350 | 350.49 | 2.379 | 250.02 | 422.2 | 1.85708 | 650 | 659.84 | 21.86 | 473.25 | 85.34 | 2.49364 |
| 360 | 360.58 | 2.626 | 257.24 | 393.4 | 1.88543 | 660 | 670.47 | 23.13 | 481.01 | 81.89 | 2.50985 |
| 370 | 370.67 | 2.892 | 264.46 | 367.2 | 1.91313 | 670 | 681.14 | 24.46 | 488.81 | 78.61 | 2.52589 |
| 380 | 380.77 | 3.176 | 271.69 | 343.4 | 1.94001 | 680 | 691.82 | 25.85 | 496.62 | 75.50 | 2.54175 |
| 390 | 390.88 | 3.481 | 278.93 | 321.5 | 1.96633 | 690 | 702.52 | 27.29 | 504.45 | 72.56 | 2.55731 |
| 400 | 400.98 | 3.806 | 286.16 | 301.6 | 1.99194 | 700 | 713.27 | 28.80 | 512.33 | 69.76 | 2.57277 |
| 410 | 411.12 | 4.153 | 293.43 | 283.3 | 2.01699 | 710 | 724.04 | 30.38 | 520.23 | 67.07 | 2.58810 |
| 420 | 421.26 | 4.522 | 300.69 | 266.6 | 2.04142 | 720 | 734.82 | 32.02 | 528.14 | 64.53 | 2.60319 |
| 430 | 431.43 | 4.915 | 307.99 | 251.1 | 2.06533 | 730 | 745.62 | 33.72 | 536.07 | 62.13 | 2.61803 |
| 440 | 441.61 | 5.332 | 315.30 | 236.8 | 2.08870 | 740 | 756.44 | 35.50 | 544.02 | 59.82 | 2.63280 |

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**TABLE A.8 (continued) Ideal Gas Properties of Air**

| $T$(K), $h$ and $u$(kJ/kg), $s^\circ$(kJ/kg·K) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^\circ$ | $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^\circ$ |
| 750 | 767.29 | 37.35 | 551.99 | 57.63 | 2.64737 | 1300 | 1395.97 | 330.9 | 1022.82 | 11.275 | 3.27345 |
| 760 | 778.18 | 39.27 | 560.01 | 55.54 | 2.66176 | 1320 | 1419.76 | 352.5 | 1040.88 | 10.747 | 3.29160 |
| 770 | 789.11 | 41.31 | 568.07 | 53.39 | 2.67595 | 1340 | 1443.60 | 375.3 | 1058.94 | 10.247 | 3.30959 |
| 780 | 800.03 | 43.35 | 576.12 | 51.64 | 2.69013 | 1360 | 1467.49 | 399.1 | 1077.10 | 9.780 | 3.32724 |
| 790 | 810.99 | 45.55 | 584.21 | 49.86 | 2.70400 | 1380 | 1491.44 | 424.2 | 1095.26 | 9.337 | 3.34474 |
| 800 | 821.95 | 47.75 | 592.30 | 48.08 | 2.71787 | 1400 | 1515.42 | 450.5 | 1113.52 | 8.919 | 3.36200 |
| 820 | 843.98 | 52.59 | 608.59 | 44.84 | 2.74504 | 1420 | 1539.44 | 478.0 | 1131.77 | 8.526 | 3.37901 |
| 840 | 866.08 | 57.60 | 624.95 | 41.85 | 2.77170 | 1440 | 1563.51 | 506.9 | 1150.13 | 8.153 | 3.39586 |
| 860 | 888.27 | 63.09 | 641.40 | 39.12 | 2.79783 | 1460 | 1587.63 | 537.1 | 1168.49 | 7.801 | 3.41247 |
| 880 | 910.56 | 68.98 | 657.95 | 36.61 | 2.82344 | 1480 | 1611.79 | 568.8 | 1186.95 | 7.468 | 3.42892 |
| 900 | 932.93 | 75.29 | 674.58 | 34.31 | 2.84856 | 1500 | 1635.97 | 601.9 | 1205.41 | 7.152 | 3.44516 |
| 920 | 955.38 | 82.05 | 691.28 | 32.18 | 2.87324 | 1520 | 1660.23 | 636.5 | 1223.87 | 6.854 | 3.46120 |
| 940 | 977.92 | 89.28 | 708.08 | 30.22 | 2.89748 | 1540 | 1684.51 | 672.8 | 1242.43 | 6.569 | 3.47712 |
| 960 | 1000.55 | 97.00 | 725.02 | 28.40 | 2.92128 | 1560 | 1708.82 | 710.5 | 1260.99 | 6.301 | 3.49276 |
| 980 | 1023.25 | 105.2 | 741.98 | 26.73 | 2.94468 | 1580 | 1733.17 | 750.0 | 1279.65 | 6.046 | 3.50829 |
| 1000 | 1046.04 | 114.0 | 758.94 | 25.17 | 2.96770 | 1600 | 1757.57 | 791.2 | 1298.30 | 5.804 | 3.52364 |
| 1020 | 1068.89 | 123.4 | 776.10 | 23.72 | 2.99034 | 1620 | 1782.00 | 834.1 | 1316.96 | 5.574 | 3.53879 |
| 1040 | 1091.85 | 133.3 | 793.36 | 22.39 | 3.01260 | 1640 | 1806.46 | 878.9 | 1335.72 | 5.355 | 3.55381 |
| 1060 | 1114.86 | 143.9 | 810.62 | 21.14 | 3.03449 | 1660 | 1830.96 | 925.6 | 1354.48 | 5.147 | 3.56867 |
| 1080 | 1137.89 | 155.2 | 827.88 | 19.98 | 3.05608 | 1680 | 1855.50 | 974.2 | 1373.24 | 4.949 | 3.58335 |
| 1100 | 1161.07 | 167.1 | 845.33 | 18.896 | 3.07732 | 1700 | 1880.1 | 1025 | 1392.7 | 4.761 | 3.5979 |
| 1120 | 1184.28 | 179.7 | 862.79 | 17.886 | 3.09825 | 1750 | 1941.6 | 1161 | 1439.8 | 4.328 | 3.6336 |
| 1140 | 1207.57 | 193.1 | 880.35 | 16.946 | 3.11883 | 1800 | 2003.3 | 1310 | 1487.2 | 3.944 | 3.6684 |
| 1160 | 1230.92 | 207.2 | 897.91 | 16.064 | 3.13916 | 1850 | 2065.3 | 1475 | 1534.9 | 3.601 | 3.7023 |
| 1180 | 1254.34 | 222.2 | 915.57 | 15.241 | 3.15916 | 1900 | 2127.4 | 1655 | 1582.6 | 3.295 | 3.7354 |
| 1200 | 1277.79 | 238.0 | 933.33 | 14.470 | 3.17888 | 1950 | 2189.7 | 1852 | 1630.6 | 3.022 | 3.7677 |
| 1220 | 1301.31 | 254.7 | 951.09 | 13.747 | 3.19834 | 2000 | 2252.1 | 2068 | 1678.7 | 2.776 | 3.7994 |
| 1240 | 1324.93 | 272.3 | 968.95 | 13.069 | 3.21751 | 2050 | 2314.6 | 2303 | 1726.8 | 2.555 | 3.8303 |
| 1260 | 1348.55 | 290.8 | 986.90 | 12.435 | 3.23638 | 2100 | 2377.4 | 2559 | 1775.3 | 2.356 | 3.8605 |
| 1280 | 1372.24 | 310.4 | 1004.76 | 11.835 | 3.25510 | 2150 | 2440.3 | 2837 | 1823.8 | 2.175 | 3.8901 |
| | | | | | | 2200 | 2503.2 | 3138 | 1872.4 | 2.012 | 3.9191 |
| | | | | | | 2250 | 2566.4 | 3464 | 1921.3 | 1.864 | 3.9474 |

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**TABLE A.8 (continued) Ideal Gas Properties of Air**

## Part b. English Units

$T$(°R), $h$ and $u$(Btu/lb), $s^o$(Btu/lb · °R)

| $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^o$ | $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^o$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 360 | 85.97 | 0.3363 | 61.29 | 396.6 | 0.50369 | 940 | 226.11 | 9.834 | 161.68 | 35.41 | 0.73509 |
| 380 | 90.75 | 0.4061 | 64.70 | 346.6 | 0.51663 | 960 | 231.06 | 10.61 | 165.26 | 33.52 | 0.74030 |
| 400 | 95.53 | 0.4858 | 68.11 | 305.0 | 0.52890 | 980 | 236.02 | 11.43 | 168.83 | 31.76 | 0.74540 |
| 420 | 100.32 | 0.5760 | 71.52 | 270.1 | 0.54058 | 1000 | 240.98 | 12.30 | 172.43 | 30.12 | 0.75042 |
| 440 | 105.11 | 0.6776 | 74.93 | 240.6 | 0.55172 | 1040 | 250.95 | 14.18 | 179.66 | 27.17 | 0.76019 |
| 460 | 109.90 | 0.7913 | 78.36 | 215.33 | 0.56235 | 1080 | 260.97 | 16.28 | 186.93 | 24.58 | 0.76964 |
| 480 | 114.69 | 0.9182 | 81.77 | 193.65 | 0.57255 | 1120 | 271.03 | 18.60 | 194.25 | 22.30 | 0.77880 |
| 500 | 119.48 | 1.0590 | 85.20 | 174.90 | 0.58233 | 1160 | 281.14 | 21.18 | 201.63 | 20.29 | 0.78767 |
| 520 | 124.27 | 1.2147 | 88.62 | 158.58 | 0.59172 | 1200 | 291.30 | 24.01 | 209.05 | 18.51 | 0.79628 |
| 537 | 128.34 | 1.3593 | 91.53 | 146.34 | 0.59945 | 1240 | 301.52 | 27.13 | 216.53 | 16.93 | 0.80466 |
| 540 | 129.06 | 1.3860 | 92.04 | 144.32 | 0.60078 | 1280 | 311.79 | 30.55 | 224.05 | 15.52 | 0.81280 |
| 560 | 133.86 | 1.5742 | 95.47 | 131.78 | 0.60950 | 1320 | 322.11 | 34.31 | 231.63 | 14.25 | 0.82075 |
| 580 | 138.66 | 1.7800 | 98.90 | 120.70 | 0.61793 | 1360 | 332.48 | 38.41 | 239.25 | 13.12 | 0.82848 |
| 600 | 143.47 | 2.005 | 102.34 | 110.88 | 0.62607 | 1400 | 342.90 | 42.88 | 246.93 | 12.10 | 0.83604 |
| 620 | 148.28 | 2.249 | 105.78 | 102.12 | 0.63395 | 1440 | 353.37 | 47.75 | 254.66 | 11.17 | 0.84341 |
| 640 | 153.09 | 2.514 | 109.21 | 94.30 | 0.64159 | 1480 | 363.89 | 53.04 | 262.44 | 10.34 | 0.85062 |
| 660 | 157.92 | 2.801 | 112.67 | 87.27 | 0.64902 | 1520 | 374.47 | 58.78 | 270.26 | 9.578 | 0.85767 |
| 680 | 162.73 | 3.111 | 116.12 | 80.96 | 0.65621 | 1560 | 385.08 | 65.00 | 278.13 | 8.890 | 0.86456 |
| 700 | 167.56 | 3.446 | 119.58 | 75.25 | 0.66321 | 1600 | 395.74 | 71.73 | 286.06 | 8.263 | 0.87130 |
| 720 | 172.39 | 3.806 | 123.04 | 70.07 | 0.67002 | 1650 | 409.13 | 80.89 | 296.03 | 7.556 | 0.87954 |
| 740 | 177.23 | 4.193 | 126.51 | 65.38 | 0.67665 | 1700 | 422.59 | 90.95 | 306.06 | 6.924 | 0.88758 |
| 760 | 182.08 | 4.607 | 129.99 | 61.10 | 0.68312 | 1750 | 436.12 | 101.98 | 316.16 | 6.357 | 0.89542 |
| 780 | 186.94 | 5.051 | 133.47 | 57.20 | 0.68942 | 1800 | 449.71 | 114.0 | 326.32 | 5.847 | 0.90308 |
| 800 | 191.81 | 5.526 | 136.97 | 53.63 | 0.69558 | 1850 | 463.37 | 127.2 | 336.55 | 5.388 | 0.91056 |
| 820 | 196.69 | 6.033 | 140.47 | 50.35 | 0.70160 | 1900 | 477.09 | 141.5 | 346.85 | 4.974 | 0.91788 |
| 840 | 201.56 | 6.573 | 143.98 | 47.34 | 0.70747 | 1950 | 490.88 | 157.1 | 357.20 | 4.598 | 0.92504 |
| 860 | 206.46 | 7.149 | 147.50 | 44.57 | 0.71323 | 2000 | 504.71 | 174.0 | 367.61 | 4.258 | 0.93205 |
| 880 | 211.35 | 7.761 | 151.02 | 42.01 | 0.71886 | 2050 | 518.61 | 192.3 | 378.08 | 3.949 | 0.93891 |
| 900 | 216.26 | 8.411 | 154.57 | 39.64 | 0.72438 | 2100 | 532.55 | 212.1 | 388.60 | 3.667 | 0.94564 |
| 920 | 221.18 | 9.102 | 158.12 | 37.44 | 0.72979 | 2150 | 546.54 | 233.5 | 399.17 | 3.410 | 0.95222 |

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**TABLE A.8 (continued) Ideal Gas Properties of Air**

$T$(°R), $h$ and $u$(Btu/lb), $s^o$(Btu/lb · °R)

| $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^o$ | $T$ | $h$ | $p_r$ | $u$ | $v_r$ | $s^o$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2200 | 560.59 | 256.6 | 409.78 | 3.176 | 0.95868 | 3700 | 998.11 | 2330 | 744.48 | .5882 | 1.10991 |
| 2250 | 574.69 | 281.4 | 420.46 | 2.961 | 0.96501 | 3750 | 1013.1 | 2471 | 756.04 | .5621 | 1.11393 |
| 2300 | 588.82 | 308.1 | 431.16 | 2.765 | 0.97123 | 3800 | 1028.1 | 2618 | 767.60 | .5376 | 1.11791 |
| 2350 | 603.00 | 336.8 | 441.91 | 2.585 | 0.97732 | 3850 | 1043.1 | 2773 | 779.19 | .5143 | 1.12183 |
| 2400 | 617.22 | 367.6 | 452.70 | 2.419 | 0.98331 | 3900 | 1058.1 | 2934 | 790.80 | .4923 | 1.12571 |
| 2450 | 631.48 | 400.5 | 463.54 | 2.266 | 0.98919 | 3950 | 1073.2 | 3103 | 802.43 | .4715 | 1.12955 |
| 2500 | 645.78 | 435.7 | 474.40 | 2.125 | 0.99497 | 4000 | 1088.3 | 3280 | 814.06 | .4518 | 1.13334 |
| 2550 | 660.12 | 473.3 | 485.31 | 1.996 | 1.00064 | 4050 | 1103.4 | 3464 | 825.72 | .4331 | 1.13709 |
| 2600 | 674.49 | 513.5 | 496.26 | 1.876 | 1.00623 | 4100 | 1118.5 | 3656 | 837.40 | .4154 | 1.14079 |
| 2650 | 688.90 | 556.3 | 507.25 | 1.765 | 1.01172 | 4150 | 1133.6 | 3858 | 849.09 | .3985 | 1.14446 |
| 2700 | 703.35 | 601.9 | 518.26 | 1.662 | 1.01712 | 4200 | 1148.7 | 4067 | 860.81 | .3826 | 1.14809 |
| 2750 | 717.83 | 650.4 | 529.31 | 1.566 | 1.02244 | 4300 | 1179.0 | 4513 | 884.28 | .3529 | 1.15522 |
| 2800 | 732.33 | 702.0 | 540.40 | 1.478 | 1.02767 | 4400 | 1209.4 | 4997 | 907.81 | .3262 | 1.16221 |
| 2850 | 746.88 | 756.7 | 551.52 | 1.395 | 1.03282 | 4500 | 1239.9 | 5521 | 931.39 | .3019 | 1.16905 |
| 2900 | 761.45 | 814.8 | 562.66 | 1.318 | 1.03788 | 4600 | 1270.4 | 6089 | 955.04 | .2799 | 1.17575 |
| 2950 | 776.05 | 876.4 | 573.84 | 1.247 | 1.04288 | 4700 | 1300.9 | 6701 | 978.73 | .2598 | 1.18232 |
| 3000 | 790.68 | 941.4 | 585.04 | 1.180 | 1.04779 | 4800 | 1331.5 | 7362 | 1002.5 | .2415 | 1.18876 |
| 3050 | 805.34 | 1011 | 596.28 | 1.118 | 1.05264 | 4900 | 1362.2 | 8073 | 1026.3 | .2248 | 1.19508 |
| 3100 | 820.03 | 1083 | 607.53 | 1.060 | 1.05741 | 5000 | 1392.9 | 8837 | 1050.1 | .2096 | 1.20129 |
| 3150 | 834.75 | 1161 | 618.82 | 1.006 | 1.06212 | 5100 | 1423.6 | 9658 | 1074.0 | .1956 | 1.20738 |
| 3200 | 849.48 | 1242 | 630.12 | .9546 | 1.06676 | 5200 | 1454.4 | 10539 | 1098.0 | .1828 | 1.21336 |
| 3250 | 864.24 | 1328 | 641.46 | .9069 | 1.07134 | 5300 | 1485.3 | 11481 | 1122.0 | .1710 | 1.21923 |
| 3300 | 879.02 | 1418 | 652.81 | .8621 | 1.07585 | | | | | | |
| 3350 | 893.83 | 1513 | 664.20 | .8202 | 1.08031 | | | | | | |
| 3400 | 908.66 | 1613 | 675.60 | .7807 | 1.08470 | | | | | | |
| 3450 | 923.52 | 1719 | 687.04 | .7436 | 1.08904 | | | | | | |
| 3500 | 938.40 | 1829 | 698.48 | .7087 | 1.09332 | | | | | | |
| 3550 | 953.30 | 1946 | 709.95 | .6759 | 1.09755 | | | | | | |
| 3600 | 968.21 | 2068 | 721.44 | .6449 | 1.10172 | | | | | | |
| 3650 | 983.15 | 2196 | 732.95 | .6157 | 1.10584 | | | | | | |

*Source:* Adapted from M.J. Moran and H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, 3rd. ed., Wiley, New York, 1995, as based on J.H. Keenan and J. Kaye, *Gas Tables*, Wiley, New York, 1945.

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## TABLE A.9 Equations for Gas Properties

| Gas | Molar Mass $M$ kg/kmol | Gas Constant $R$ kJ/kg·K | Specific Heats at 25°C $c_p$ kJ/kg·K | $c_v$ kJ/kg·K | $k$ | Equation Coefficients for $c_p/R = a + bT + cT^2 + dT^3 + eT^4$ Temperature Range | $a$ | $b \times 10^3$ $K^{-1}$ | $c \times 10^6$ $K^{-2}$ | $d \times 10^{10}$ $K^{-3}$ | $e \times 10^{13}$ $K^{-4}$ | Critical State Properties $p_c$ MPa | $T_c$ K | Redlich–Kwong Constants $a$ kPa·m$^6$·K$^{0.5}$/kmol$^2$ | $b$ m$^3$/kmol | Gas |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acetylene, $C_2H_2$ | 26.04 | 0.319 | 1.69 | 1.37 | 1.232 | 300–1000K | 0.8021 | 23.51 | −35.95 | 286.1 | −87.64 | 6.14 | 308 | 8030 | 0.0362 | Acetylene, $C_2H_2$ |
| | | | | | | 1000–3000K | 3.825 | 6.767 | −3.014 | 6.931 | −0.6469 | | | | | |
| Air | 28.97 | 0.287 | 1.01 | 0.718 | 1.400 | 300–1000K | 3.721 | −1.874 | 4.719 | −34.45 | 8.531 | 3.77 | 132 | 1580 | 0.0253 | Air |
| | | | | | | 1000–3000K | 2.786 | 1.925 | −0.9465 | 2.321 | −0.2229 | | | | | |
| Argon, Ar | 39.95 | 0.208 | 0.520 | 0.312 | 1.667 | | 2.50 | 0 | 0 | 0 | 0 | 4.90 | 151 | 1680 | 0.0222 | Argon, Ar |
| Butane, $C_4H_{10}$ | 58.12 | 0.143 | 1.67 | 1.53 | 1.094 | 300–1500K | 0.4756 | 44.65 | −22.04 | 42.07 | 0 | 3.80 | 425 | 29000 | 0.0806 | Butane, $C_4H_{10}$ |
| Carbon Dioxide $CO_2$ | 44.01 | 0.189 | 0.844 | 0.655 | 1.289 | 300–1000K | 2.227 | 9.992 | −9.802 | 53.97 | −12.81 | 7.38 | 304 | 6450 | 0.0297 | Carbon Dioxide $CO_2$ |
| | | | | | | 1000–3000K | 3.247 | 5.847 | −3.412 | 9.469 | −1.009 | | | | | |
| Carbon Monoxide CO | 28.01 | 0.297 | 1.04 | 0.744 | 1.399 | 300–1000K | 3.776 | −2.093 | 4.880 | −32.71 | 6.984 | 3.50 | 133 | 1720 | 0.0274 | Carbon Monoxide, CO |
| | | | | | | 1000–3000K | 2.654 | 2.226 | −1.146 | 2.851 | −0.2762 | | | | | |
| Ethane, $C_2H_6$ | 30.07 | 0.276 | 1.75 | 1.48 | 1.187 | 300–1500K | 0.8293 | 20.75 | −7.704 | 8.756 | 0 | 4.88 | 306 | 9860 | 0.0450 | Ethane, $C_2H_6$ |
| Ethylene, $C_2H_4$ | 28.05 | 0.296 | 1.53 | 1.23 | 1.240 | 300–1000K | 1.575 | 10.19 | 11.25 | −199.1 | 81.98 | 5.03 | 282 | 7860 | 0.0404 | Ethylene, $C_2H_4$ |
| | | | | | | 1000–3000K | 0.2530 | 18.67 | −9.978 | 26.03 | −2.668 | | | | | |
| Helium, He | 4.003 | 2.08 | 5.19 | 3.12 | 1.667 | | 2.50 | 0 | 0 | 0 | 0 | 0.228 | 5.20 | 8.00 | 0.0165 | Helium, He |
| Hydrogen, $H_2$ | 2.016 | 4.12 | 14.3 | 10.2 | 1.405 | 300–1000K | 2.892 | 3.884 | −8.850 | 86.94 | −29.88 | 1.31 | 33.2 | 143 | 0.0182 | Hydrogen, $H_2$ |
| | | | | | | 1000–3000K | 3.717 | −0.9220 | 1.221 | −4.328 | 0.5202 | | | | | |
| Hydrogen, H | 1.008 | 8.25 | 20.6 | 12.4 | 1.667 | 300–1000K | 2.496 | 0.02977 | −0.07655 | 0.8238 | −0.3158 | | | | | Hydrogen, H |
| | | | | | | 1000–3000K | 2.567 | −0.1509 | 0.1219 | −0.4184 | 0.05182 | | | | | |
| Hydroxyl, OH | 17.01 | 0.489 | 1.76 | 1.27 | 1.384 | 300–1000K | 3.874 | −1.349 | 1.670 | −5.670 | 0.6189 | | | | | Hydroxyl, OH |
| | | | | | | 1000–3000K | 3.229 | 0.2014 | 0.4357 | −2.043 | 0.2696 | | | | | |
| Methane, $CH_4$ | 16.04 | 0.518 | 2.22 | 1.70 | 1.304 | 300–1000K | 4.503 | −8.965 | 37.38 | −364.9 | 122.2 | 4.60 | 191 | 3210 | 0.0298 | Methane, $CH_4$ |
| | | | | | | 1000–3000K | −0.6992 | 15.31 | −7.695 | 18.96 | −1.849 | | | | | |
| Neon, Ne | 20.18 | 0.412 | 1.03 | 0.618 | 1.667 | | 2.50 | 0 | 0 | 0 | 0 | 2.65 | 44.4 | 146 | 0.0120 | Neon, Ne |
| Nitric Oxide, NO | 30.01 | 0.277 | 0.995 | 0.718 | 1.386 | 300–1000K | 4.120 | −4.225 | 10.77 | −97.64 | 31.85 | 6.48 | 180 | 1980 | 0.0200 | Nitric Oxide, NO |
| | | | | | | 1000–3000K | 2.730 | 2.372 | −1.338 | 3.604 | −0.3743 | | | | | |
| Nitrogen, $N_2$ | 28.01 | 0.297 | 1.04 | 0.743 | 1.400 | 300–1000K | 3.725 | −1.562 | 3.208 | −15.54 | 1.154 | 3.39 | 126 | 1550 | 0.0267 | Nitrogen, $N_2$ |
| | | | | | | 1000–3000K | 2.469 | 2.467 | −1.312 | 3.401 | −0.3454 | | | | | |
| Nitrogen, N | 14.01 | 0.594 | 1.48 | 0.890 | 1.667 | 300–1000K | 2.496 | 0.02977 | −0.07655 | 0.8238 | −0.3158 | | | | | Nitrogen, N |
| | | | | | | 1000–3000K | 2.483 | 0.03033 | −0.01517 | 0.001879 | 0.009657 | | | | | |
| Oxygen, $O_2$ | 32.00 | 0.260 | 0.919 | 0.659 | 1.395 | 300–1000K | 3.837 | −3.420 | 10.99 | −109.6 | 37.47 | 5.04 | 155 | 1740 | 0.0221 | Oxygen, $O_2$ |
| | | | | | | 1000–3000K | 3.156 | 1.809 | −1.052 | 3.190 | −0.3629 | | | | | |
| Oxygen, O | 16.00 | 0.520 | 1.37 | 0.850 | 1.612 | 300–1000K | 3.020 | −2.176 | 3.793 | −30.62 | 9.402 | | | | | Oxygen, O |
| | | | | | | 1000–3000K | 2.662 | −0.3051 | 0.2250 | −0.7447 | 0.09383 | | | | | |
| Propane, $C_3H_8$ | 44.10 | 0.189 | 1.67 | 1.48 | 1.127 | 300-1500K | -0.4861 | 36.63 | -18.91 | 38.14 | 0 | 4.26 | 370 | 18300 | 0.0626 | Propane, $C_3H_8$ |
| Water, $H_2O$ | 18.02 | 0.462 | 1.86 | 1.40 | 1.329 | 300–1000K | 4.132 | −1.559 | 5.315 | −42.09 | 12.84 | 22.1 | 647 | 14300 | 0.0211 | Water, $H_2O$ |
| | | | | | | 1000–3000K | 2.798 | 2.693 | −0.5392 | −0.01783 | 0.09027 | | | | | |

*Source:* Adapted from J.B. Jones and R.E. Dugan, *Engineering Thermodynamics*, Prentice-Hall, Englewood Cliffs, NJ 1996 from various sources: *JANAF Thermochemical Tables*, 3rd ed., published by the American Chemical Society and the American Institute of Physics for the National Bureau of Standards, 1986. Data for butane, ethane, and propane from K.A. Kobe and E.G. Long, "Thermochemistry for the Petrochemical Industry, Part II — Paraffinic Hydrocarbons, $C_1$–$C_{16}$" *Petroleum Refiner*, Vol. 28, No. 2, 1949, pp. 113–116.

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# Appendix B. Properties of Liquids

**TABLE B.1 Properties of Liquid Water***

## Symbols and Units:

$\rho$ = density, lbm/ft$^3$. For g/cm$^3$ multiply by 0.016018. For kg/m$^3$ multiply by 16.018.
$c_p$ = specific heat, Btu/lbm·deg R = cal/g·K. For J/kg·K multiply by 4186.8
$\mu$ = viscosity. For lbf·sec/ft$^2$ = slugs/sec·ft, multiply by $10^{-7}$. For lbm·sec·ft multiply by $10^{-7}$ and by 32.174. For g/sec·cm (poises) multiply by $10^{-7}$ and by 478.80. For N·sec/m$^2$ multiply by $10^{-7}$ and by 478.880.
$k$ = thermal conductivity, Btu/hr·ft·deg R. For W/m·K multiply by 1.7307.

| *Temp,* °F | *At 1 atm or 14.7 psia* | | | | *At 1,000 psia* | | | | *At 10,000 psia* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\rho$ | $c_p$ | $\mu$ | $k$ | $\rho$ | $c_p$ | $\mu$ | $k$ | $\rho$ | $c_p$ | $\mu$ | $k$† |
| 32 | 62.42 | 1.007 | 366 | 0.3286 | 62.62 | 0.999 | 365 | 0.3319 | 64.5 | 0.937 | 357 | 0.3508 |
| 40 | 62.42 | 1.004 | 323 | 0.334 | 62.62 | 0.997 | 323 | 0.337 | 64.5 | 0.945 | 315 | 0.356 |
| 50 | 62.42 | 1.002 | 272 | 0.3392 | 62.62 | 0.995 | 272 | 0.3425 | 64.5 | 0.951 | 267 | 0.3610 |
| 60 | 62.38 | 1.000 | 235 | 0.345 | 62.58 | 0.994 | 235 | 0.348 | 64.1 | 0.956 | 233 | 0.366 |
| 70 | 62.31 | 0.999 | 204 | 0.350 | 62.50 | 0.994 | 204 | 0.353 | 64.1 | 0.960 | 203 | 0.371 |
| 80 | 62.23 | 0.998 | 177 | 0.354 | 62.42 | 0.994 | 177 | 0.358 | 64.1 | 0.962 | 176 | 0.376 |
| 90 | 62.11 | 0.998 | 160 | 0.359 | 62.31 | 0.994 | 160 | 0.362 | 63.7 | 0.964 | 159 | 0.380 |
| 100 | 62.00 | 0.998 | 142 | 0.3633 | 62.19 | 0.994 | 142 | 0.3666 | 63.7 | 0.965 | 142 | 0.3841 |
| 110 | 61.88 | 0.999 | 126 | 0.367 | 62.03 | 0.994 | 126 | 0.371 | 63.7 | 0.966 | 126 | 0.388 |
| 120 | 61.73 | 0.999 | 114 | 0.371 | 61.88 | 0.995 | 114 | 0.374 | 63.3 | 0.967 | 114 | 0.391 |
| 130 | 61.54 | 0.999 | 105 | 0.374 | 61.73 | 0.995 | 105 | 0.378 | 63.3 | 0.968 | 105 | 0.395 |
| 140 | 61.39 | 0.999 | 96 | 0.378 | 61.58 | 0.996 | 96 | 0.381 | 63.3 | 0.969 | 98 | 0.398 |
| 150 | 61.20 | 1.000 | 89 | 0.3806 | 61.39 | 0.996 | 89 | 0.3837 | 63.0 | 0.970 | 91 | 0.4003 |
| 160 | 61.01 | 1.001 | 83 | 0.383 | 61.20 | 0.997 | 83 | 0.386 | 62.9 | 0.971 | 85 | 0.403 |
| 170 | 60.79 | 1.002 | 77 | 0.386 | 60.98 | 0.998 | 77 | 0.389 | 62.5 | 0.972 | 79 | 0.405 |
| 180 | 60.57 | 1.003 | 72 | 0.388 | 60.75 | 0.999 | 72 | 0.391 | 62.5 | 0.973 | 74 | 0.407 |
| 190 | 60.35 | 1.004 | 68 | 0.390 | 60.53 | 1.001 | 68 | 0.393 | 62.1 | 0.974 | 70 | 0.409 |
| 200 | 60.10 | 1.005 | 62.5 | 0.3916 | 60.31 | 1.002 | 62.9 | 0.3944 | 62.1 | 0.975 | 65.4 | 0.4106 |
| 250 | boiling point 212°F | | | | 59.03 | 1.001 | 47.8 | 0.3994 | 60.6 | 0.981 | 50.6 | 0.4158 |
| 300 | | | | | 57.54 | 1.024 | 38.4 | 0.3993 | 59.5 | 0.988 | 41.3 | 0.4164 |
| 350 | | | | | 55.83 | 1.044 | 32.1 | 0.3944 | 58.1 | 0.999 | 35.1 | 0.4132 |
| 400 | | | | | 53.91 | 1.072 | 27.6 | 0.3849 | 56.5 | 1.011 | 30.6 | 0.4064 |
| 500 | | | | | 49.11 | 1.181 | 21.6 | 0.3508 | 52.9 | 1.051 | 24.8 | 0.3836 |
| 600 | | | | | boiling point 544.58°F | | | | 48.3 | 1.118 | 21.0 | 0.3493 |

†At 7,500 psia.

*From: "1967 ASME Steam Tables", American Society of Mechanical Engineers, Tables 9, 10, and 11 and Figures 6, 7, 8, and 9.

The ASME compilation is a 330-page book of tables and charts, including a $2\frac{1}{2} \times 3\frac{1}{2}$-ft Mollier chart. All values have been computed in accordance with the 1967 specifications of the International Formulation Committee (IFC) and are in conformity with the 1963 International Skeleton Tables. This standardization of tables began in 1921 and was extended through the International Conferences in London (1929), Berlin (1930), Washington (1934), Philadelphia (1954), London (1956), New York (1963) and Glasgow (1966). Based on these world-wide standard data, the 1967 ASME volume represents detailed computer output in both tabular and graphic form. Included are density and volume, enthalpy, entropy, specific heat, viscosity, thermal conductivity, Prandtl number, isentropic exponent, choking velocity, p-v product, etc., over the entire range (to 1500 psia 1500°F). English units are used, but all conversion factors are given.

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**TABLE B.2 Physical and Thermal Properties of Common Liquids**

## Part a. SI Units

(At 1.0 Atm Pressure (0.101 325 $MN/m^2$), 300 K, except as noted.)

| *Common name* | *Density, $kg/m^3$* | *Specific heat, $kJ/kg \cdot K$* | *Viscosity, $N \cdot s/m^2$* | *Thermal conductivity, $W/m \cdot K$* | *Freezing point, K* | *Latent heat of fusion, kJ/kg* | *Boiling point, K* | *Latent heat of evaporation, kJ/kg* | *Coefficient of cubical expansion per K* |
|---|---|---|---|---|---|---|---|---|---|
| Acetic acid | 1 049 | 2.18 | .001 155 | 0.171 | 290 | 181 | 391 | 402 | 0.001 1 |
| Acetone | 784.6 | 2.15 | .000 316 | 0.161 | 179.0 | 98.3 | 329 | 518 | 0.001 5 |
| Alcohol, ethyl | 785.1 | 2.44 | .001 095 | 0.171 | 158.6 | 108 | 351.46 | 846 | 0.001 1 |
| Alcohol, methyl | 786.5 | 2.54 | .000 56 | 0.202 | 175.5 | 98.8 | 337.8 | 1 100 | 0.001 4 |
| Alcohol, propyl | 800.0 | 2.37 | .001 92 | 0.161 | 146 | 86.5 | 371 | 779 | |
| Ammonia (aqua) | 823.5 | 4.38 | | 0.353 | | | | | |
| Benzene | 873.8 | 1.73 | .000 601 | 0.144 | 278.68 | 126 | 353.3 | 390 | 0.001 3 |
| Bromine | | .473 | .000 95 | | 245.84 | 66.7 | 331.6 | 193 | 0.001 2 |
| Carbon disulfide | 1 261 | .992 | .000 36 | 0.161 | 161.2 | 57.6 | 319.40 | 351 | 0.001 3 |
| Carbon tetrachloride | 1 584 | .866 | .000 91 | 0.104 | 250.35 | 174 | 349.6 | 194 | 0.001 3 |
| Castor oil | 956.1 | 1.97 | .650 | 0.180 | 263.2 | | | | |
| Chloroform | 1 465 | 1.05 | .000 53 | 0.118 | 209.6 | 77.0 | 334.4 | 247 | 0.001 3 |
| Decane | 726.3 | 2.21 | .000 859 | 0.147 | 243.5 | 201 | 447.2 | 263 | |
| Dodecane | 754.6 | 2.21 | .001 374 | 0.140 | 247.18 | 216 | 489.4 | 256 | |
| Ether | 713.5 | 2.21 | .000 223 | 0.130 | 157 | 96.2 | 307.7 | 372 | 0.001 6 |
| Ethylene glycol | 1 097 | 2.36 | .016 2 | 0.258 | 260.2 | 181 | 470 | 800 | |
| Fluorine refrigerant R-11 | 1 476 | .870[a] | .000 42 | 0.093[a] | 162 | | 297.0 | 180[b] | |
| Fluorine refrigerant R-12 | 1 311 | .971[a] | | 0.071[a] | 115 | 34.4 | 243.4 | 165[b] | |
| Fluorine refrigerant R-22 | 1 194 | 1.26[a] | | 0.086[a] | 113 | 183 | 232.4 | 232[b] | |
| Glycerine | 1 259 | 2.62 | .950 | 0.287 | 264.8 | 200 | 563.4 | 974 | 0.000 54 |
| Heptane | 679.5 | 2.24 | .000 376 | 0.128 | 182.54 | 140 | 371.5 | 318 | |
| Hexane | 654.8 | 2.26 | .000 297 | 0.124 | 178.0 | 152 | 341.84 | 365 | |
| Iodine | | 2.15 | | | 386.6 | 62.2 | 457.5 | 164 | |
| Kerosene | 820.1 | 2.09 | .001 64 | 0.145 | | | | 251 | |
| Linseed oil | 929.1 | 1.84 | .033 1 | | 253 | | 560 | | |
| Mercury | | .139 | .001 53 | | 234.3 | 11.6 | 630 | 295 | 0.000 18 |
| Octane | 698.6 | 2.15 | .000 51 | 0.131 | 216.4 | 181 | 398 | 298 | 0.000 72 |
| Phenol | 1 072 | 1.43 | .008 0 | 0.190 | 316.2 | 121 | 455 | | 0.000 90 |
| Propane | 493.5 | 2.41[a] | .000 11 | | 85.5 | 79.9 | 231.08 | 428[b] | |
| Propylene | 514.4 | 2.85 | .000 09 | | 87.9 | 71.4 | 225.45 | 342 | |
| Propylene glycol | 965.3 | 2.50 | .042 | | 213 | | 460 | 914 | |
| Sea water | 1 025 | 3.76–4.10 | | | 270.6 | | | | |
| Toluene | 862.3 | 1.72 | .000 550 | 0.133 | 178 | 71.8 | 383.6 | 363 | |
| Turpentine | 868.2 | 1.78 | .001 375 | 0.121 | 214 | | 433 | 293 | 0.000 99 |
| Water | 997.1 | 4.18 | .000 89 | 0.609 | 273 | 333 | 373 | 2 260 | 0.000 20 |

[a] At 297 K, liquid.
[b] At .101 325 meganewtons, saturation temperature.

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**TABLE B.2 (continued) Physical and Thermal Properties of Common Liquids**

## Part b. English Units

(At 1.0 Atm Pressure 77°F (25°C), except as noted.)

For viscosity in N·s/m² (=kg m·s), multiply values in centipoises by 0.001. For surface tension in N/m, multiply values in dyne/cm by 0.001.

| *Common name* | *Density,* $\frac{lb}{ft^3}$ | *Specific gravity* | *Viscosity* | | *Sound velocity,* $\frac{meters}{sec}$ | *Dielectric constant* | *Refractive index* |
|---|---|---|---|---|---|---|---|
| | | | $lb_m/ft\ sec \times 10^4$ | *cp* | | | |
| Acetic acid | 65.493 | 1.049 | 7.76 | 1.155 | $1584^{50}$ | 6.15 | 1.37 |
| Acetone | 48.98 | .787 | 2.12 | 0.316 | 1174 | 20.7 | 1.36 |
| Alcohol, ethyl | 49.01 | .787 | 7.36 | 1.095 | 1144 | 24.3 | 1.36 |
| Alcohol, methyl | 49.10 | .789 | 3.76 | 0.56 | 1103 | 32.6 | 1.33 |
| Alcohol, propyl | 49.94 | .802 | 12.9 | 1.92 | 1205 | 20.1 | 1.38 |
| Ammonia (aqua) | 51.411 | .826 | — | — | — | 16.9 | — |
| Benzene | 54.55 | .876 | 4.04 | 0.601 | 1298 | 2.2 | 1.50 |
| Bromine | — | — | 6.38 | 0.95 | — | 3.20 | — |
| Carbon disulfide | 78.72 | 1.265 | 2.42 | 0.36 | 1149 | 2.64 | 1.63 |
| Carbon tetrachloride | 98.91 | 1.59 | 6.11 | 0.91 | 924 | 2.23 | 1.46 |
| Castor oil | 59.69 | 0.960 | — | 650 | 1474 | 4.7 | — |
| Chloroform | 91.44 | 1.47 | 3.56 | 0.53 | 995 | 4.8 | 1.44 |
| Decane | 45.34 | .728 | 5.77 | 0.859 | — | 2.0 | 1.41 |
| Dodecane | 47.11 | — | 9.23 | 1.374 | — | — | 1.41 |
| Ether | 44.54 | 0.715 | 1.50 | 0.223 | 985 | 4.3 | 1.35 |
| Ethylene glycol | 68.47 | 1.100 | 109 | 16.2 | 1644 | 37.7 | 1.43 |
| Fluorine refrigerant R-11 | 92.14 | 1.480 | 2.82 | 0.42 | — | 2.0 | 1.37 |
| Fluorine refrigerant R-12 | 81.84 | 1.315 | — | — | — | 2.0 | 1.29 |
| Fluorine refrigerant R-22 | 74.53 | 1.197 | — | — | — | 2.0 | 1.26 |
| Glycerine | 78.62 | 1.263 | 6380 | 950 | 1909 | 40 | 1.47 |
| Heptane | 42.42 | .681 | 2.53 | 0.376 | 1138 | 1.92 | 1.38 |
| Hexane | 40.88 | .657 | 2.00 | 0.297 | 1203 | — | 1.37 |
| Iodine | — | — | — | — | — | 11 | — |
| Kerosene | 51.2 | 0.823 | 11.0 | 1.64 | 1320 | — | — |
| Linseed oil | 58.0 | 0.93 | 222 | 33.1 | — | 3.3 | — |
| Mercury | — | 13.633 | 10.3 | 1.53 | 1450 | — | — |
| Octane | 43.61 | .701 | 3.43 | 0.51 | 1171 | — | 1.40 |
| Phenol | 66.94 | 1.071 | 54 | 8.0 | $1274^{100}$ | 9.8 | — |
| Propane | 30.81 | .495 | 0.74 | 0.11 | — | 1.27 | 1.34 |
| Propylene | 32.11 | .516 | 0.60 | 0.09 | — | — | 1.36 |
| Propylene glycol | 60.26 | .968 | — | 42 | — | — | 1.43 |
| Sea water | 64.0 | 1.03 | — | — | 1535 | — | — |
| Toluene | 53.83 | 0.865 | 3.70 | 0.550 | $1275^{30}$ | 2.4 | 1.49 |
| Turpentine | 54.2 | 0.87 | 9.24 | 1.375 | 1240 | — | 1.47 |
| Water | 62.247 | 1.00 | 6.0 | 0.89 | 1498 | 78.54[a] | 1.33 |

[a]The dielectric constant of water near the freezing point is 87.8; it decreases with increase in temperature to about 55.6 near the boiling point.

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# Appendix C. Properties of Solids

**TABLE C.1 Properties of Common Solids***

| Material | Specific gravity | Specific heat | | Thermal conductivity | |
|---|---|---|---|---|---|
| | | $\frac{Btu}{lbm \cdot deg\ R}$ | $\frac{kJ}{kg \cdot K}$ | $\frac{Btu}{hr \cdot ft \cdot deg\ F}$ | $\frac{W}{m \cdot K}$ |
| Asbestos cement board | 1.4 | 0.2 | .837 | 0.35 | 0.607 |
| Asbestos millboard | 1.0 | 0.2 | .837 | 0.08 | 0.14 |
| Asphalt | 1.1 | 0.4 | 1.67 | | |
| Beeswax | 0.95 | 0.82 | 3.43 | | |
| Brick, common | 1.75 | 0.22 | .920 | 0.42 | 0.71 |
| Brick, hard | 2.0 | 0.24 | 1.00 | 0.75 | 1.3 |
| Chalk | 2.0 | 0.215 | .900 | 0.48 | 0.84 |
| Charcoal, wood | 0.4 | 0.24 | 1.00 | 0.05 | 0.088 |
| Coal, anthracite | 1.5 | 0.3 | 1.26 | | |
| Coal, bituminous | 1.2 | 0.33 | 1.38 | | |
| Concrete, light | 1.4 | 0.23 | .962 | 0.25 | 0.42 |
| Concrete, stone | 2.2 | 0.18 | .753 | 1.0 | 1.7 |
| Corkboard | 0.2 | 0.45 | 1.88 | 0.025 | 0.04 |
| Earth, dry | 1.4 | 0.3 | 1.26 | 0.85 | 1.5 |
| Fiberboard, light | 0.24 | 0.6 | 2.51 | 0.035 | 0.058 |
| Fiber hardboard | 1.1 | 0.5 | 2.09 | 0.12 | 0.2 |
| Firebrick | 2.1 | 0.25 | 1.05 | 0.8 | 1.4 |
| Glass, window | 2.5 | 0.2 | .837 | 0.55 | 0.96 |
| Gypsum board | 0.8 | 0.26 | 1.09 | 0.1 | 0.17 |
| Hairfelt | 0.1 | 0.5 | 2.09 | 0.03 | 0.050 |
| Ice (32°) | 0.9 | 0.5 | 2.09 | 1.25 | 2.2 |
| Leather, dry | 0.9 | 0.36 | 1.51 | 0.09 | 0.2 |
| Limestone | 2.5 | 0.217 | .908 | 1.1 | 1.9 |
| Magnesia (85%) | 0.25 | 0.2 | .837 | 0.04 | 0.071 |
| Marble | 2.6 | 0.21 | .879 | 1.5 | 2.6 |
| Mica | 2.7 | 0.12 | .502 | 0.4 | 0.71 |
| Mineral wool blanket | 0.1 | 0.2 | .837 | 0.025 | 0.04 |
| Paper | 0.9 | 0.33 | 1.38 | 0.07 | 0.1 |
| Paraffin wax | 0.9 | 0.69 | 2.89 | 0.15 | 0.2 |
| Plaster, light | 0.7 | 0.24 | 1.00 | 0.15 | 0.2 |
| Plaster, sand | 1.8 | 0.22 | .920 | 0.42 | 0.71 |
| Plastics, foamed | 0.2 | 0.3 | 1.26 | 0.02 | 0.03 |
| Plastics, solid | 1.2 | 0.4 | 1.67 | 0.11 | 0.19 |
| Porcelain | 2.5 | 0.22 | .920 | 0.9 | 1.5 |
| Sandstone | 2.3 | 0.22 | .920 | 1.0 | 1.7 |
| Sawdust | 0.15 | 0.21 | .879 | 0.05 | 0.08 |
| Silica aerogel | 0.11 | 0.2 | .837 | 0.015 | 0.02 |
| Vermiculite | 0.13 | 0.2 | .837 | 0.035 | 0.058 |
| Wood, balsa | 0.16 | 0.7 | 2.93 | 0.03 | 0.050 |
| Wood, oak | 0.7 | 0.5 | 2.09 | 0.10 | 0.17 |
| Wood, white pine | 0.5 | 0.6 | 2.51 | 0.07 | 0.12 |
| Wool, felt | 0.3 | 0.33 | 1.38 | 0.04 | 0.071 |
| Wool, loose | 0.1 | 0.3 | 1.26 | 0.02 | 0.3 |

*Compiled from several sources.

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## TABLE C.2 Density of Various Solids:* Approximate Density of Solids at Ordinary Atmospheric Temperature

| *Substance* | *Grams per cu cm* | *Pounds per cu ft* |
|---|---|---|
| Agate | 2.5–2.7 | 156–168 |
| Alabaster | | |
| Carbonate | 2.69-2.78 | 168–173 |
| Sulfate | 2.26–2.32 | 141 145 |
| Albite | 2.62 2.65 | 163–165 |
| Amber | 1.06 1.11 | 66–69 |
| Amphiboles | 2.9 3.2 | 180–200 |
| Anorthite | 2.74–2.76 | 171 -172 |
| Asbestos | 2.0 2.8 | 125–175 |
| Asbestos slate | 1.8 | 112 |
| Asphalt | 1.1–1.5 | 69–94 |
| Basalt | 2.4–3.1 | 150–190 |
| Beeswax | 0.96–0.97 | 60–61 |
| Beryl | 2.69–2.7 | 168–169 |
| Biotite | 2.7–3.1 | 170–190 |
| Bone | 1.7–2.0 | 106–125 |
| Brick | 1.4–2.2 | 87–137 |
| Butter | 0.86–0.87 | 53-54 |
| Calamine | 4.1–4.5 | 255–280 |
| Calcspar | 2.6 2.8 | 162–175 |
| Camphor | 0.99 | 62 |
| Caoutchouc | 0.92–0.99 | 57–62 |
| Cardboard | 0.69 | 43 |
| Celluloid | 1.4 | 87 |
| Cement, set | 2.7–3.0 | 170–190 |
| Chalk | 1.9–2.8 | 118–175 |
| Charcoal | | |
| Oak | 0.57 | 35 |
| Pine | 0.28–0.44 | 18–28 |
| Cinnabar | 8.12 | 507 |
| Clay | 1.8–2.6 | 112–162 |
| Coal | | |
| Anthracite | 1.4 1.8 | 87–112 |
| Bituminous | 1.2–1.5 | 75–94 |
| Cocoa butter | 0.89 0.91 | 56–57 |
| Coke | 1.0–1.7 | 62–105 |
| Copal | 1.04–1.14 | 65–71 |
| Cork | 0.22 0.26 | 14–16 |
| Cork linoleum | 0.54 | 34 |
| Corundum | 3.9–4.0 | 245–250 |
| Diamond | 3.01–3.52 | 188–220 |
| Dolomite | 2.84 | 177 |
| Ebonite | 1.15 | 72 |
| Emery | 4.0 | 250 |
| Epidote | 3.25–3.50 | 203–218 |
| Feldspar | 2.55–2.75 | 159–172 |
| Flint | 2.63 | 164 |
| Fluorite | 3.18 | 198 |
| Galena | 7.3–7.6 | 460–470 |
| Gamboge | 1.2 | 75 |
| Garnet | 3.15–4.3 | 197–268 |
| Gas carbon | 1.88 | 117 |
| Gelatin | 1.27 | 79 |
| Glass | | |
| Common | 2.4–2.8 | 150–175 |
| Flint | 2.9 5.9 | 180–370 |
| Glue | 1.27 | 79 |
| Granite | 2.64 2.76 | 165-172 |
| Graphite† | 2.30–2.72 | 144–170 |
| Gum arabic | 1.3 1.4 | 81–87 |
| Gypsum | 2.31-2.33 | 144–145 |
| Hematite | 4.9 5.3 | 306–330 |
| Hornblende | 3.0 | 187 |
| Ice | 0.917 | 57.2 |
| Ivory | 1.83–1.92 | 114-120 |
| Leather, dry | 0.86 | 54 |
| Lime, slaked | 1.3–1.4 | 81 87 |
| Limestone | 2.68–2.76 | 167–171 |
| Linoleum | 1.18 | 74 |
| Magnetite | 4.9–5.2 | 306–324 |
| Malachite | 3.7–4.1 | 231–256 |
| Marble | 2.6–2.84 | 160 177 |
| Meerschaum | 0.99 1.28 | 62–80 |
| Mica | 2.6–3.2 | 165–200 |
| Muscovite | 2.76–3.00 | 172–187 |
| Ochre | 3.5 | 218 |
| Opal | 2.2 | 137 |
| Paper | 0.7–1.15 | 44–72 |
| Paraffin | 0.87–0.91 | 54–57 |
| Peat blocks | 0.84 | 52 |
| Pitch | 1.07 | 67 |
| Porcelain | 2.3 2.5 | 143–156 |
| Porphyry | 2.6–2.9 | 162–181 |
| Pressed wood pulp board | 0.19 | 12 |
| Pyrite | 4.95 5.1 | 309–318 |
| Quartz | 2.65 | 165 |
| Resin | 1.07 | 67 |
| Rock salt | 2.18 | 136 |
| Rubber, hard | 1.19 | 74 |
| Rubber, soft | | |
| Commercial | 1.1 | 69 |
| Pure gum | 0.91–0.93 | 57–58 |
| Sandstone | 2.14–2.36 | 134–147 |
| Serpentine | 2.50–2.65 | 156–165 |
| Silica | | |
| Fused transparent | 2.21 | 138 |
| Translucent | 2.07 | 129 |
| Slag | 2.0–3.9 | 125–240 |
| Slate | 2.6–3.3 | 162–205 |
| Soapstone | 2.6-2.8 | 162–175 |
| Spermaceti | 0.95 | 59 |
| Starch | 1.53 | 95 |
| Sugar | 1.59 | 99 |
| Talc | 2.7–2.8 | 168–174 |
| Tallow | | |
| Beef | 0.94 | 59 |
| Mutton | 0.94 | 59 |
| Tar | 1.02 | 66 |
| Topaz | 3.5–3.6 | 219 223 |
| Tourmaline | 3.0–3.2 | 190 200 |
| Wax, sealing | 1.8 | 112 |
| Wood (seasoned) | | |
| Alder | 0.42–0.68 | 26–42 |
| Apple | 0.66–0.84 | 41–52 |
| Ash | 0.65 0.85 | 40–53 |
| Balsa | 0.11 0.14 | 7–9 |
| Bamboo | 0.31–0.40 | 19 25 |
| Basswood | 0.32–0.59 | 20–37 |
| Beech | 0.70–0.90 | 32–56 |
| Birch | 0.51–0.77 | 32 48 |
| Blue gum | 1.00 | 62 |
| Box | 0.95–1.16 | 59–72 |
| Butternut | 0.38 | 24 |
| Cedar | 0.49–0.57 | 30 35 |
| Cherry | 0.70–0.90 | 43–56 |
| Dogwood | 0.76 | 47 |
| Ebony | 1.11–1.33 | 69–83 |
| Elm | 0.54–0.60 | 34 37 |
| Hickory | 0.60–0.93 | 37–58 |
| Holly | 0.76 | 47 |
| Juniper | 0.56 | 35 |
| Larch | 0.50–0.56 | 31–35 |
| Lignum vitae | 1.17–1.33 | 73 83 |
| Locust | 0.67–0.71 | 42–44 |
| Logwood | 0.91 | 57 |
| Mahogany | | |
| Honduras | 0.66 | 41 |
| Spanish | 0.85 | 53 |
| Maple | 0.62–0.75 | 39–47 |
| Oak | 0.60–0.90 | 37–56 |
| Pear | 0.61–0.73 | 38–45 |
| Pine | | |
| Pitch | 0.83–0.85 | 52 53 |
| White | 0.35–0.50 | 22–31 |
| Yellow | 0.37–0.60 | 23–37 |
| Plum | 0.66–0.78 | 41–49 |
| Poplar | 0.35–0.5 | 22 31 |
| Satinwood | 0.95 | 59 |
| Spruce | 0.48–0.70 | 30–44 |
| Sycamore | 0.40–0.60 | 24–37 |
| Teak | | |
| Indian | 0.66–0.88 | 41 55 |
| African | 0.98 | 61 |
| Walnut | 0.64–0.70 | 40–43 |
| Water gum | 1.00 | 62 |
| Willow | 0.40–0.60 | 24–37 |

†Some values reported as low as 1.6

*Based largely on: "Smithsonian Physical Tables", 9th rev. ed., W.E. Forsythe, Ed., The Smithsonian Institution, 1956, p. 292.

*Note:* In the case of substances with voids, such as paper or leather, the bulk density is indicated rather than the density of the solid portion. For density in kg/m$^3$, multiply values in g/cm$^3$ by 1,000.

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**TABLE C.3 Specific Stiffness of Metals, Alloys, and Certain Non-Metallics***

Specific stiffness is usually expressed as the modulus of elasticity (in tension) per unit weight-density, i.e., $E/\rho$, in units of pounds and inches. While the stiffness of similar alloys varies considerably, there are definite ranges and groups to be recognized. Since the specific stiffness of steel is about 100 million, the values in the following table are also approximately the percentage stiffness, referred to steel.

| *Material* | *Specific stiffness, millions* |
|---|---|
| Beryllium | 650 |
| Silicon carbide | 600 |
| Alumina ceramics | 400 |
| Mica | 350 |
| Titanium carbide cermet | 250 |
| Alumina cermet | 200 |
| Molybdenum and alloys; silica glass | 130 |
| Titanium and alloys; cobalt superalloys; soda-lime glass | 110 |
| Carbon and low-alloy steel; wrought iron | 105 |
| Stainless steel; nodular cast iron; magnesium and alloys; aluminum and alloys | 100 |
| Nickel and alloys; malleable iron | 95 |
| Iron silicon alloys (cast); iridium; vanadium | 90 |
| Monel alloys; tungsten | 80 |
| Gray cast iron; columbium alloys | 70 |
| Aluminum bronze; beryllium copper | 65 |
| Nickel silver; cupronickel; zirconium | 55 |
| Yellow brass; nickel cast iron; bronze; Muntz metal; antimony | 50 |
| Copper; red brass; tantalum | 45 |
| Silver and alloys; pewter; platinum and alloys; white gold | 30 |
| Tin; thorium | 25 |
| Gold | 20 |
| Tin-lead alloy | 10 |
| Lead | 5 |

*Compiled from several sources.

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## TABLE C.4 Thermal Properties of Pure Metals—Metric Units

| Metal | AT ATMOSPHERIC PRESSURE | | | | | | | | LIQUID METAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | At 100°K | | At 25°C (77°F) | | | | Vapor pressure | | |
| | Melting point, °C | Boiling point, °C | Latent heat of fusion, cal/g** | Thermal conductivity, watts/cm °C | Specific heat, cal/g °C** | Specific heat, cal/g °C** | Coeff. of linear expansion, ($\times 10^6$) $(°C)^{-1}$ | Thermal conductivity, watts/cm °C | Specific heat (liquid) at 2000°K, cal/g °C** | $10^{-3}$ atm | $10^{-6}$ atm | $10^{-9}$ atm |
| | | | | | | | | | | Boiling point temperatures, °K | | |
| Aluminum | 660. | 2441. | 95 | 3.00* | .115 | 0.215 | 25 | 2.37 | .26 | 1,782 | 1,333 | 1,063 |
| Antimony | 630. | 1440. | 38.5 | — | .040 | .050 | 9 | .185 | .062 | 1,007 | 741 | 612 |
| Beryllium | 1285. | 2475. | 324. | — | .049 | .436 | 12 | 2.18 | .78 | 1,793 | 1,347 | 1,085 |
| Bismuth | 271.4 | 1660. | 12.4 | — | .026 | .030 | 13 | .084 | .036 | 1,155 | 851 | 677 |
| Cadmium | 321. | 767. | 13.2 | 1.03 | .047 | .055 | 30 | .93 | .063 | 655 | 486 | 388 |
| Chromium | 1860. | 2670. | 79 | 1.58 | .046 | .110 | 6 | .91 | .224 | 1,992 | 1,530 | 1,247 |
| Cobalt | 1495. | 2925. | 66 | — | .057 | .10 | 12 | .69 | .164 | 2,167 | 1,652 | 1,345 |
| Copper | 1084. | 2575. | 49 | 4.83* | .061 | .092 | 16.6 | 3.98 | .118 | 1,862 | 1,391 | 1,120 |
| Gold | 1063. | 2800. | 15 | 3.45* | .026 | .031 | 14.2 | 3.15 | .0355 | 2,023 | 1,510 | 1,211 |
| Iridium | 2450. | 4390. | 33 | — | .022 | .031 | 6 | 1.47 | .0434 | 3,253 | 2,515 | 2,062 |
| Iron | 1536. | 2870. | 65 | 1.32* | .052 | .108 | 12 | .803 | .197 | 2,093 | 1,594 | 1,297 |
| Lead | 327.5 | 1750. | 5.5 | 0.396 | .028 | .031 | 29 | .346 | .033 | 1,230 | 889 | 698 |
| Magnesium | 650. | 1090. | 88.0 | 1.69 | .016 | .243 | 25 | 1.59 | .32 | 857 | 638 | 509 |
| Manganese | 1244. | 2060. | 64 | — | .064 | .114 | 22 | — | .20 | 1,495 | 1,131 | 913 |
| Mercury | −38.86 | 356.55 | 2.7 | — | .029 | .033 | — | .0839 | — | 393 | 287 | 227 |
| Molybdenum | 2620. | 4651. | 69 | 1.79 | .033 | .060 | 5 | 1.4 | .089 | 3,344 | 2,558 | 2,079 |
| Nickel | 1453. | 2800. | 71 | 1.58 | .055 | .106 | 13 | .899 | .175 | 2,156 | 1,646 | 1,343 |
| Niobium (Columbium) | 2470. | 4740. | 68 | 0.552 | .045 | .064 | 7 | .52 | .083 | 3,523 | 2,721 | 2,232 |
| Osmium | 3025. | 4225. | 34 | — | — | .031 | 5 | .61 | .039 | — | — | — |
| Platinum | 1770. | 3825. | 24 | 0.79* | .024 | .032 | 9 | .73 | .043 | 2,817 | 2,155 | 1,757 |
| Plutonium | 640. | 3230. | 3 | — | .019 | .032 | 54 | .08 | .041 | 2,200 | 1,596 | 1,252 |
| Potassium | 63.3 | 760. | 14.5 | — | .150 | .180 | 83 | .99 | — | 606 | 430 | 335 |
| Rhodium | 1965. | 3700. | 50 | — | — | .058 | 8 | 1.50 | .092 | — | — | — |
| Selenium | 217. | 700. | 16 | — | — | .077 | 37 | .005 | — | — | — | — |
| Silicon | 1411. | 3280. | 430 | — | .062 | .17 | 3 | .835 | .217 | 2,340 | 1,749 | 1,427 |
| Silver | 961. | 2212. | 26.5 | 4.50* | .045 | .057 | 19 | 4.27 | .068 | 1,582 | 1,179 | 952 |
| Sodium | 97.83 | 884. | 27 | — | .234 | .293 | 70 | 1.34 | — | 701 | 504 | 394 |
| Tantalum | 2980. | 5365. | 41 | 0.592 | .026 | .034 | 6.5 | .54 | .040 | 3,959 | 3,052 | 2,495 |
| Thorium | 1750. | 4800. | 17 | — | .024 | .03 | 12 | .41 | .047 | 3,251 | 2,407 | 1,919 |
| Tin | 232. | 2600. | 14.1 | 0.85 | .039 | .054 | 20 | .64 | .058 | 1,857 | 1,366 | 1,080 |
| Titanium | 1670. | 3290. | 100 | 0.312 | .072 | .125 | 8.5 | .2 | .188 | 2,405 | 1,827 | 1,484 |
| Tungsten | 3400. | 5550. | 46 | 2.35* | .021 | .032 | 4.5 | 1.78 | .040 | 4,139 | 3,228 | 2,656 |
| Uranium | 1132. | 4140. | 12 | — | .022 | .028 | 13.4 | .25 | .048 | 2,861 | 2,128 | 1,699 |
| Vanadium | 1900. | 3400. | 98 | — | .061 | .116 | 8 | .60 | .207 | 2,525 | 1,948 | 1,591 |
| Zinc | 419.5 | 910. | 27 | 1.32 | .063 | .093 | 35 | 1.15 | — | 752 | 559 | 449 |

* Temperatures of maximum thermal conductivity (conductivity values in watts/cm °C): Aluminum 13°K, cond. = 71.5; copper 10°K, cond. = 196; gold 10°K, cond. = 28.2; iron 20°K, cond. = 9.97; platinum 8°K, cond. = 12.9; silver 7°K, cond. = 193; tungsten 8°K, cond. = 85.3.

** To convert to SI units note that 1 cal = 4.186 J.



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## TABLE C.5 Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials

For $MN/m^2$ multiply strength in thousands of psi by 6.895.

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties: Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | **FERROUS ALLOYS** | | | | | |
| | Ferrous alloys comprise the largest volume of metal alloys used in engineering. The actual range of mechanical properties in any particular grade of alloy steel depends on the particular history and heat treatment. The steels listed in this table are intended to give some idea of the range of properties readily obtainable. Many hundreds of steels are available. Cost is frequently an important criterion in the choice of material; in general the greater the percentage of alloying elements present in the alloy, the greater will be the cost. | | | | | | | |
| | *IRON* | | | | | | | |
| 1 | Ingot iron (Included for comparison) | Fe 99.9 | Hot-rolled<br>Annealed | 29<br>19 | 45<br>38 | 26<br>45 | 90<br>67 | |
| | *PLAIN CARBON STEELS* | | | | | | | |
| 2 | AISI-SAE 1020 | C 0.20 Mn 0.45<br>Si 0.25 Fe bal. | Hot-rolled<br>Hardened (water-quenched, 1000°F-tempered) | 30<br>62 | 55<br>90 | 25<br>25 | 111<br>179 | Bolts, crankshafts, gears, connecting rods; easily weldable |
| 3 | AISI 1025 | C 0.25 Fe bal.<br>Mn 0.45 | Bar stock<br>Hot-rolled<br>Cold-drawn | <br>32<br>54 | <br>58<br>64 | <br>25<br>15 | <br>116<br>126 | |
| 4 | AISI-SAE 1035 | C 0.35 Mn 0.75 | Hot-rolled<br>Cold-rolled | 39<br>67 | 72<br>80 | 18<br>12 | 143<br>163 | Medium-strength, engineering steel |
| 5 | AISI-SAE 1045 | C 0.45 Fe bal.<br>Mn 0.75 | Bar stock<br>Annealed<br>Hot-rolled<br>Cold-drawn | <br>73<br>45<br>77 | <br>80<br>82<br>91 | <br>12<br>16<br>12 | <br>170<br>163<br>179 | |
| 6 | AISI-SAE 1078 | C 0.78 Fe bal.<br>Mn 0.45 | Bar stock<br>Hot-rolled; spheroidized<br>Annealed | <br>55<br>72 | <br>100<br>94 | <br>12<br>10 | <br>207<br>192 | |
| 7 | AISI-SAE 1095 | C 0.95 Fe bal.<br>Mn 0.40 | | | | | | |
| 8 | AISI-SAE 1120 | C 0.2 Mn 0.8<br>S 0.1 | Cold-drawn | 58 | 69 | — | 137 | Free-cutting, leaded, resulphurized steel; high-speed, automatic machining |
| | *ALLOY STEELS* | | | | | | | |
| 9 | ASTM A202/56 | C 0.17 Mn 1.2<br>Cr 0.5 Si 0.75 | Stress-relieved | 45 | 75 | 18 | — | Low alloy; boilers, pressure vessels |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| *No.* | *Material* | *Nominal composition* | *Form and condition* | *Typical mechanical properties* | | | | *Comments* |
|---|---|---|---|---|---|---|---|---|
| | | | | *Yield strength (0.2% offset), 1000 lb/sq in.* | *Tensile strength, 1000 lb/sq in.* | *Elongation, in 2 in., %* | *Hardness, Brinell* | |
| 10 | AISI 4140 | C 0.40 Si 0.3<br>Cr 1.0 Mo 0.2<br>Mn 0.9 | Fully-tempered<br>Optimum properties | 95<br>132 | 108<br>150 | 22<br>18 | 240<br>— | High strength; gears, shafts |
| 11 | 12% Manganese steel | 12% Mn C | Tempered 600°F<br>Rolled and heat-treated stock | 200<br>44 | 220<br>160 | 10<br>40 | —<br>170 | Machine tool parts; wear, abrasion-resistant |
| 12 | VASCO 300 | Ni 18.5 Ti 0.6<br>Co 9.0 C 0.03<br>Mo 4.8 | Solution treatment 1500°F; aged 900°F | 110 | 150 | 18 | — | Very high strength, maraging, good machining properties in annealed state |
| 13 | T1 (AISI) | W 18.0 V 1.0<br>Cr 4.0 C 0.7 | Quenched; tempered | | | | R(c) | High speed tool steel, cutting tools, punches, etc. |
| 14 | M2 (AISI) | W 6.5 Mo 5.0<br>Cr 4.0 C 0.85<br>V 2.0 | Quenched; tempered | | | | 65–66 | M-grade, cheaper, tougher |
| 15 | Stainless steel type 304 | Ni 9.0 C 0.08<br>Cr 19.0 max | Annealed; cold-rolled | 35<br>to<br>160 | 85<br>to<br>185 | 60<br>8 | 160<br>to<br>400 | General purpose, weldable; nonmagnetic austenitic steel |
| 16 | Stainless steel type 316 | Cr 18.0 C 0.10<br>Ni 11.0 max<br>Mo 2.5 Fe bal. | Annealed | 30<br>to<br>120 | 90<br>to<br>150 | 50<br>8 | 165<br>275 | For severe corrosive media, under stress; nonmagnetic austenitic steel |
| 17 | Stainless steel type 431 | Cr 16.0 Si 1.0<br>Ni 2.0 C 0.20<br>Mn 1.0 Fe bal. | Annealed<br>Heat-treated | 85<br>150 | 120<br>195 | 25<br>20 | 250<br>400 | Heat-treated stainless steel, with good mechanical strength; magnetic |
| 18 | Stainless steel 17–4 PH | Cr 17.0 Co 0.35<br>Ni 4.0 C 0.07<br>Cu 4.0 Fe bal. | Annealed | 110 | 150 | 10 | 363 | Precipitation hardening; heat-resisting type; retains strength up to approx. 600°F |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| *No.* | *Material* | *Nominal composition* | *Form and condition* | *Typical mechanical properties* | | | | *Comments* |
|---|---|---|---|---|---|---|---|---|
| | | | | *Yield strength (0.2% offset), 1000 lb/sq in.* | *Tensile strength, 1000 lb/sq in.* | *Elongation, in 2 in., %* | *Hardness, Brinell* | |
| | | | **CAST IRONS AND CAST STEELS** | | | | | |
| | These alloys are used where large and/or intricate-shaped articles are required or where over-all dimensional tolerances are not critical. Thus the article can be produced with the fabrication and machining costs held to a minimum. Except for a few heat-treatable cast steels, this class of alloys does not demonstrate high-strength qualities. | | | | | | | |
| | *CAST IRONS* | | | | | | | |
| 19 | Cast gray iron ASTM A48-48, Class 25 | C 3.4 Si 1.8 Mn 0.5 | Cast (as cast) | — | 25 min | 0.5 max | 180 | Engine blocks, fly-wheels, gears, machine-tool bases |
| 20 | White | C 3.4 Si 0.7 Mn 0.6 | Cast | — | 25 | 0 | 450 | |
| 21 | Malleable iron ASTM A47 | C 2.5 Si 1.0 Mn 0.55 max | Cast (annealed) | 33 | 52 | 12 | 130 | Automotives, axle bearings, track wheels, crankshafts |
| 22 | Ductile or nodular iron (Mg-containing) | C 3.4 P 0.1 max | Cast | 53 | 70 | 18 | 170 | Heavy-duty machines, gears, cams, crankshafts |
| | ASTM A339 | Mn 0.40 | Cast (as cast) | 68 | 90 | 7 | 235 | |
| | ASTM A395 | Ni 1% Mg 0.06 Si 2.5 Fe bal. | Cast (quenched, tempered) | 108 | 135 | 5 | 310 | |
| 23 | Ni-hard type 2 | C 2.7 Si 0.6 Mn 0.5 Ni 4.5 Cr 2.0 Fe bal. | Sand-cast | — | 55 | — | 550 | Strength, with heat- and corrosion-resistance |
| | | | Chill-cast (tempered) | — | 75 | — | 625 | |
| 24 | Ni-resist type 2 | C 3.0 Si 2.0 Mn 1.0 Ni 20.0 Cr 2.5 Fe bal. | Cast (as cast) | — | 27 | 2 | 140 | |
| | *CAST STEELS* | | | | | | | |
| 25 | ASTM A27-62 (60-30) | C 0.3 Mn 0.6 Si 0.8 Ni 0.5 Cr 0.4 Mo 0.2 | | 30 | 60 | 24 | — | Low alloy, medium strength, general application |
| 26 | ASTM A148-60 (105-85) | | | 85 | 105 | 17 | — | High strength; structural application |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties: Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | Comments |
|---|---|---|---|---|---|---|---|---|
| 27 | Cast 12 Cr alloy (CA-15) | C 0.15 max; Mn 1.00 max; Si 1.50 max; Cr 11.5–14; Ni 1.00 max; Fe bal. | Air-cooled from 1800°F; tempered at 600°F | 150 | 200 | 7 | 390 | Stainless, corrosion-resistant to mildly corrosive alkalis and acids |
| | | | Air-cooled from 1800°F; tempered at 1400°F | 75 | 100 | 30 | 185 | |
| 28 | Cast 29-9 alloy (CE-30) ASTM A296 63T | C 0.30 max; Mn 1.50 max; Si 2.00 max; Cr 26–30; Ni 8–11; Fe bal. | As cast | 60 | 95 | 15 | 170 | Greater corrosion resistance, especially for oxidizing condition |
| 29 | Cast 28-7 alloy (HD) ASTM A297-63T | C 0.50 max; Mn 1.50 max; Si 2.00 max; Cr 26–30; Ni 4–7; Fe bal. | As cast | 48 | 85 | 16 | 190 | Heat-resistant |

## SUPER ALLOYS

The advent of engineering applications requiring high temperature and high strength, as in jet engines and rocket motors, has lead to the development of a range of alloys collectively called super alloys. These alloys require excellent resistance to oxidation together with strength at high temperatures, typically 1800°F in existing engines. These alloys are continually being modified to develop better specific properties, and therefore entries in this group of alloys should be considered "fluid". Both wrought and casting-type alloys are represented. As the high temperature properties of cast materials improve, these alloys become more attractive, since great dimensional precision is now attainable in investment castings.

| No. | Material | Nominal composition | Form and condition | Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | Comments |
|---|---|---|---|---|---|---|---|---|
| | *NICKEL BASE* | | | | | | | |
| 30 | Hastelloy X | Co 1.5 max; Fe 18.5; Cr 22.0; Mo 9.0; W 0.6; C 0.15 max (wrought); C 0.20 max (cast); Ni bal. | Wrought sheet | 52 | 113.2 | 43 | 194 | |
| | | | Mill-annealed | — | 67 | 17 | 172 | |
| | | | As investment cast | 46.5 | — | — | — | |
| 31 | Hastelloy C | Cr 16.0; Fe 6.0; W 4.0; C 0.15 max; Mo 17.0; Ni bal. | Sand-cast (annealed) | 50 | 78 | 5 | 199 | |
| | | | Rolled (annealed) | 71 | 130 | 45 | 204 | |
| | | | Investment cast | 50 | 80 | 10 | 215 | |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties | | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | |
| | *NICKEL BASE (Cont.)* | | | | | | | |
| 32 | Inconel 713C | Ni (+Co) bal. Cr 13.0 Cb 2.0 Mo 4.5 Ti 0.6 Al 6.0 | Investment cast | 102 | 120 | 6 | — | |
| 33 | In 100 | C 18.0 Cr 10.0 Mo 3.0 Ti 4.7 Al 55.0 Co 15.0 V 1.0 | Cast | | | | | |
| 34 | Taz 8 | C 125.0 Cr 6.0 Mo 4.0 Al 6.0 W 4.0 Zr 1.0 Ta 8.0 V 2.5 | Cast | | | | | |
| 35 | Nimonic 90 | Ni (+Co) 57.00 C 0.05 Fe 0.45 Mn 0.50 Si 0.20 S 0.007 Cr 20.55 Cu 0.05 Ti 2.60 Al 1.65 Co 16.90 | Annealed; wrought | 90 | 155 | — | 260 | General elevated temperature applications |
| 36 | Inconel X | Ni (+Co) 72.85 C 0.04 Fe 6.80 Mn 0.65 Si 0.30 S 0.007 Cr 15.0 Cu 0.05 Ti 2.50 Al 0.75 Cb (+Ta) 0.85 | Annealed<br>Annealed; age-hardened | 50<br>115 | 115<br>175 | 50<br>25 | 150<br>300 | |
| 37 | Waspaloy | C 0.08 Cr 19.5 Mo 4.3 Ti 3.0 Co 13.5 | Cold-rolled | 270 | 275 | 8 | Rc 51 | |
| 38 | Rene 41 | C 0.09 Cr 19.0 Mo 10.0 Ti 3.1 Al 1.5 Co 11.0 | Wrought | 100 | 145 | — | — | |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties: Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | Comments |
|---|---|---|---|---|---|---|---|---|
| 39 | Udimet 700 | C 0.08 Cr 15.0 Mo 5.0 Ti 3.5 Al 4.3 Co 18.5 | Cold-rolled | 280 | 285 | 6 | Rc 53 | |
| 40 | T.D. Nickel | Ni 97.5 $ThO_2$ 2.4 | Extended and cold-worked | 85 | 100 | 13 | — | High temperature; jet engine parts |
| | *COBALT BASE* | | | | | | | |
| 41 | Haynes Stellite alloy 25 (L605) | C 0.15 max Cr 20.0 W 15.0 Ni 10.0 Co bal. Mn 1.5 | Wrought sheet; mill annealed | 63 | 140 | 60 | 244 | Wrought products |
| 42 | Haynes Stellite alloy 21 AMS 5385 (cast) | C 0.25 Mo 5.5 Ni 2.5 Co bal. Cr 28.5 | As investment cast | 82 | 103 | 8 | 313 max | For castings |
| | **ALUMINUM ALLOYS** | | | | | | | |
| | Although the strength of aluminum alloys is in general less than that attainable in ferrous alloys or copper-base alloys, their major advantage lies in their high strength-to-weight ratio due to the low density of aluminum. Aluminum alloys have good corrosion resistance for most applications except in alkaline solutions. | | | | | | | |
| 43 | 3003 ASTM B221 | Cu 0.12 Al bal. Mn 1.2 | Annealed-O<br>Cold-rolled-H14<br>Cold-rolled-H18 | 6<br>21<br>27 | 16<br>22<br>29 | 40<br>16<br>10 | 28<br>40<br>55 | Good formability, weldable, medium strength; chemical equipment |
| 44 | 2017 ASTM B221 | Mn 0.5 Mg 0.5 Cu 4.0 Al bal. | Annealed-O<br>Heat-treated-T4 | 10<br>40 | 26<br>62 | 22<br>22 | 45<br>105 | High strength; structural parts, aircraft, heavy forgings |
| 45 | 2024 ASTM B211 | Cu 4.5 Mg 1.5 Mn 0.6 Al bal. | Heat-treated-T4 | 47 | 68 | 19 | 120 | |
| 46 | 5052 ASTM B211 | Cr 0.25 Al bal. Mg 2.5 | Annealed-O<br>Cold-rolled and stabilized-H34 | 13<br>31 | 28<br>38 | 30<br>14 | 47<br>68 | Medium strength, good fatigue properties; street-light standards |
| 47 | ASTM B209 | | Cold-rolled and stabilized-H38 | 37 | 42 | 8 | 77 | |

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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties | | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | |
| 48 | 7075<br>ASTM B211 | Cu 1.6 Mg 2.5<br>Cr 0.3 Al bal.<br>Zn 5.6 | Annealed-O<br>Heat-treated and artificially aged-T6 | 15<br>73 | 33<br>83 | 17<br>11 | 60<br>150 | High strength, good corrosion resistance |
| 49 | 380<br>ASTM SC84B | Si 9.0 Al bal.<br>Cu 3.5 | Die-cast | 24 | 48 | 3 | — | General purpose die casting |
| 50 | 195<br>ASTM C4A | Si 0.8 Al bal.<br>Cu 4.5 | Sand-cast; heat-treated-T4<br>Sand-cast; heat-treated and artificially aged-T6 | 16<br>24 | 32<br>36 | 8.5<br>5 | 60<br>75 | Structural elements, aircraft, and machines |
| 51 | 214<br>ASTM G4A | Mg 3.8 Al bal. | Sand-cast-F | 12 | 25 | 9 | 50 | Chemical equipment, marine hardware, architectural |
| 52 | 220<br>ASTM G10A | Mg 10.0 Al bal. | Sand-cast; heat-treated-T4 | 26 | 48 | 16 | 75 | Strength with shock resistance; aircraft |
| | **COPPER ALLOYS** | | | | | | | |
| | Because of their corrosion resistance and the fact that copper alloys have been used for many thousands of years, the number of copper alloys available is second only to the ferrous alloys. In general copper alloys do not have the high-strength qualities of the ferrous alloys, while their density is comparable. The cost per strength-weight ratio is high; however, they have the advantage of ease of joining by soldering, which is not shared by other metals that have reasonable corrosion resistance. | | | | | | | |
| 53 | Copper<br>ASTM B152<br>ASTM B124, B133<br>ASTM B1, B2, B3 | Cu 99.9 plus | Annealed<br>Cold-drawn<br>Cold-rolled | 10<br>40<br>40 | 32<br>45<br>46 | 45<br>15<br>5 | 42<br>90<br>100 | Bus-bars, switches, architectural, roofing, screens |
| 54 | Gilding metal<br>ASTM B36 | Cu 95.0 Zn 5.0 | Cold-rolled | 50 | 56 | 5 | 114 | Coinage, ammunition |
| 55 | Cartridge 70–30 brass<br>ASTM B14<br>ASTM B19<br>ASTM B36<br>ASTM B134<br>ASTM B135 | Cu 70.0 Zn 30.0 | Cold-rolled | 63 | 76 | 8 | 155 | Good cold-working properties; radiator covers, hardware, electrical |
| 56 | Phosphor bronze 10%<br>ASTM B103<br>ASTM B139<br>ASTM B159 | Cu 90.0 Sn 10.0<br>P 0.25 | Spring temper | — | 122 | 4 | 241 | Good spring qualities, high-fatigue strength |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties | | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | |
| 57 | Yellow brass (high brass)<br>ASTM B36<br>ASTM B134<br>ASTM B135 | Cu 65.0 Zn 35.0 | Annealed<br>Cold-drawn<br>Cold-rolled (HT) | 18<br>55<br>60 | 48<br>70<br>74 | 60<br>15<br>10 | 55<br>115<br>180 | Good corrosion resistance; plumbing, architectural |
| 58 | Manganese bronze<br>ASTM B138 | Cu 58.5 Zn 39.2<br>Fe 1.0 Sn 1.0<br>Mn 0.3 | Annealed<br>Cold-drawn | 30<br>50 | 60<br>80 | 30<br>20 | 95<br>180 | Forgings |
| 59 | Naval brass<br>ASTM B21 | Cu 60.0 Zn 39.25<br>Sn 0.75 | Annealed<br>Cold-drawn | 22<br>40 | 56<br>65 | 40<br>35 | 90<br>150 | Condensor tubing; high resistance to salt-water corrosion |
| 60 | Muntz metal<br>ASTM B111 | Cu 60.0 Zn 40.0 | Annealed | 20 | 54 | 45 | 80 | Condensor tubes; valve stress |
| 61 | Aluminum bronze<br>ASTM B169, alloy A<br>ASTM B124<br>ASTM B150 | Cu 92.0 Al 8.0 | Annealed<br>Hard | 25<br>65 | 70<br>105 | 60<br>7 | 80<br>210 | |
| 62 | Beryllium copper 25<br>ASTM B194<br>ASTM B197<br>ASTM B196 | Be 1.9 Cu bal.<br>Co or Ni 0.25 | Annealed, solution-treated<br>Cold-rolled<br>Cold-rolled | 32<br>104<br>70 | 70<br>110<br>190 | 45<br>5<br>3 | B60 (Rockwell)<br>B81<br>C40 | Bellows, fuse clips, electrical relay parts, valves, pumps |
| 63 | Free-cutting brass | Cu 62.0 Zn 35.5<br>Pb 2.5 | Cold-drawn | 44 | 70 | 18 | B80 (Rockwell) | Screws, nuts, gears, keys |
| 64 | Nickel silver 18%<br>Alloy A (wrought)<br>ASTM B122, No. 2 | Cu 65.0 Zn 17.0<br>Ni 18.0 | Annealed<br>Cold-rolled<br>Cold-drawn wire | 25<br>70<br>— | 58<br>85<br>105 | 40<br>4<br>— | 70<br>170<br>— | Hardware, optical goods, camera parts |
| 65 | Nickel silver 13% (cast)<br>10A<br>ASTM B149, No. 10A | Ni 12.5 Pb 9.0<br>Sn 2.0 Cu bal.<br>Zn 20.0 | Cast | 18 | 35 | 15 | 55 | Ornamental castings, plumbing; good machining qualities |
| 66 | Cupronickel 10%<br>ASTM B111<br>ASTM B171 | Cu 88.35 Ni 10.0<br>Fe 1.25 Mn 0.4 | Annealed<br>Cold-drawn tube | 22<br>57 | 44<br>60 | 45<br>15 | —<br>— | Condensor, salt-water piping |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties | | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | |
| 67 | Cupronickel | Cu 70.0 Ni 30.0 | Wrought | | | | | Heat-exchanger process equipment, valves |
| 68 | Red brass (cast) ASTM B30, No. 4A | Cu 85.0 Zn 5.0 Pb 5.0 Sn 5.0 | As-cast | 17 | 35 | 25 | 60 | |
| 69 | Silicon bronze ASTM B30, alloy 12A | Si 4.0 Fe 2.0 Zn 4.0 Al 1.0 Mn 1.0 | Castings | | | | | Cheaper substitute for tin bronze |
| 70 | Tin bronze ASTM B30, alloy 1B | Sn 8% Zn 4.0 | Castings | | | | | Bearings, high-pressure bushings, pump impellers |
| 71 | Navy bronze | | Cast | | | | | |
| | **TIN AND LEAD-BASE ALLOYS** | | | | | | | |
| | Major uses for these alloys are as "white"-metal bearing alloys, extruded cable sheathing, and solders. Tin forms the basis of pewter used for culinary applications. | | | | | | | |
| 72 | Lead-base Babbitt ASTM B23, alloy 19 | Pb 85.0 Sn 5.0 Sb 10.0 As 0.6 Cu 0.5 | Chill cast | — | 10 | 5 | 19 | Bearings, light loads and low speeds |
| 73 | Arsenical-lead Babbitt ASTM B23, alloy 15 | Pb 83.0 Sn 1.0 Sb 16.0 As 1.1 Cu 0.6 | Chill cast | — | 10.3 | 2 | 20 | Bearings, high loads and speeds, diesel engines, steel mills |
| 74 | Chemical lead | Pb 99.9 Cu 0.06 Bi 0.005 max | Rolled 95% | 1.9 | 2.5 | 50 | 5 | |
| 75 | Antimonial lead (hard lead) | Pb 94.0 Sb 6.0 | Chill cast<br>Rolled 95% | —<br>— | 6.8<br>4.1 | 22<br>47 | (500 kg)<br>9 | Good corrosion resistance and strength |
| 76 | Calcium lead | Pb 99.9 Ca 0.025 Cu 0.10 | Extruded and aged | — | 4.5 | 25 | — | Cable sheathing, creep-resistant pipe |
| 77 | Tin Babbitt alloy ASTM B23-61, grade 1 | Sb 4.5 Sn bal. Cu 4.5 | Chill cast | — | 9.3 | 2 | 17 | General bearings and die casting |
| 78 | Tin die-casting alloy ASTM B102-52 | Sb 13.0 Sn bal. Cu 5.0 | Die-cast | — | 10 | 1 | 29 | Die-casting alloy |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties | | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | |
| 79 | Pewter | Sn 91.0 Sb 7.0 Cu 2.0 | Rolled sheet, annealed | — | 8.6 | 40 | 9.5 | Ornamental and household items |
| 80 | Solder 50–50 | Sn 50.0 Pb 50.0 | Cast | 4.8 | 6.1 | 60 | 14 | General-purpose solder |
| 81 | Solder | Sn 20.0 Pb 80.0 | Cast | 3.6 | 5.8 | 16 | 11 | Coating and joining, filling seams on automobile bodies |
| | | | **MAGNESIUM ALLOYS** | | | | | |
| | Because of their low density these alloys are attractive for use where weight is at a premium. The major drawback to the use of these alloys is their ability to ignite in air (this can be a problem in machining); they are also costly. Magnesium alloys are used in both the wrought and die-cast forms, the latter being the most frequently used form. | | | | | | | |
| 82 | Magnesium alloy AZ31B | Zn 1.0 Mn 0.20 min Al 3.0 Mg bal. | Rolled-plate (strain-hardened, then partially annealed) | 24 | 37 | 18 | — | Structural applications of medium strength |
| | | | Rolled-sheet (strain-hardened, then partially annealed) | 32 | 42 | 15 | 73 | |
| | | | Annealed | 22 | 37 | 21 | 56 | |
| | | | Extruded | 28 | 38 | 14 | — | |
| 83 | Magnesium alloy AZ80A | Zn 0.5 Mn 0.15 min Al 8.5 Mg bal. | Extruded | 36 | 49 | 11 | 60 | General extruded and forged products |
| | | | Extruded (age-hardened) | 39 | 53 | 6 | 82 | |
| | | | Forged (age-hardened) | 34 | 50 | 6 | 72 | |
| 84 | Magnesium alloy AZ92A | Zn 2.0 Mn 0.10 min Al 9.0 Mg bal. | Sand-cast (as cast) | 14 | 24 | 6 | 50 | |
| | | | Sand-cast (solution heat-treated) | 14 | 40 | 12 | 55 | |
| | | | Sand-cast (solution heat-treated and aged) | 19 | 40 | 5 | 83 | |
| | | | Sand-cast (age-hardened) | 16 | 30 | 18 | — | |
| | | | Sand-cast and tempered | 22 | 40 | 3 | 81 | Pressure-tight sand and permanent mold castings; high UTS and good yield strength |
| 85 | Magnesium alloy ZK60A | Zn 5.7 Mg bal. Zr 0.55 | Extruded | 43 | 52 | 12 | 82 | |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties: Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | Comments |
|---|---|---|---|---|---|---|---|---|
| 86 | Magnesium alloy AZ91A and AZ91B | Zn 0.6 Mn 0.13 min<br>Al 9.0 Mg bal. | Die-cast (as cast) | 22 | 33 | 3 | 67 | General die-casting applications |
| | | | **BERYLLIUM** | | | | | |
| 87 | Beryllium | | | 27 | 33 | 1–3 | — | Windows, X-ray tubes |
| | | | Hot-pressed | 38 | 51 | | | |
| | | | Cross-rolled | 40 | 60 | 10–40 | — | Moderator- and reflector-cladding nuclear reactors; heat-shield and structural-member missiles |
| | | | | 60 | 90 | | | |
| | | | **NICKEL ALLOYS** | | | | | |
| | Nickel and its alloys are expensive and used mainly either for their high-corrosion resistance in many environments or for high-temperature and strength applications. (See Super Alloys, above.) | | | | | | | |
| 88 | Nickel (cast) | Ni 95.6 Cu 0.5<br>Fe 0.5 Mn 0.8<br>Si 1.5 C 0.8 | As cast | 25 | 57 | 22 | 110 | Good corrosion-resistance applications |
| 89 | K Monel | Ni (+Co) 65.25 C 0.15<br>Mn 0.60 Fe 1.00<br>S 0.005 Si 0.15<br>Cu 29.60 Al 2.75<br>Ti 0.45 | Annealed | 45 | 100 | 40 | 155 | High strength and corrosion resistance; aircraft parts, valve stems, pumps |
| | | | Annealed, age-hardened | 100 | 155 | 25 | 270 | |
| | | | Spring | 140 | 150 | 5 | 300 | |
| | | | Spring, age-hardened | 160 | 185 | 10 | 335 | |
| 90 | A nickel<br>ASTM B160<br>ASTM B161<br>ASTM B162 | Ni (+Co) 99.40 C 0.06<br>Fe 0.15<br>Mn 0.25 Si 0.05<br>S 0.005<br>Cu 0.05 | Annealed | 20 | 70 | 40 | 100 | Chemical industry for resistance to strong alkalis, plating nickel |
| | | | Hot-rolled | 25 | 75 | 40 | 110 | |
| | | | Cold-drawn | 70 | 95 | 25 | 170 | |
| | | | Cold-rolled | 95 | 105 | 5 | 210 | |
| 91 | Duranickel | Ni (+Co) 93.90 C 0.15<br>Fe 0.15<br>Mn 0.25 Si 0.55<br>S 0.005 Al 4.50<br>Cu 0.05<br>Ti 0.45 | Annealed | 45 | 100 | 40 | 160 | High strength and corrosion resistance; pump rods, shafts, springs |
| | | | Annealed, age-hardened | 125 | 170 | 25 | 330 | |
| | | | Spring | — | 175 | 5 | 320 | |
| | | | Spring, age-hardened | — | 205 | 10 | 370 | |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| No. | Material | Nominal composition | Form and condition | Typical mechanical properties: Yield strength (0.2% offset), 1000 lb/sq in. | Tensile strength, 1000 lb/sq in. | Elongation, in 2 in., % | Hardness, Brinell | Comments |
|---|---|---|---|---|---|---|---|---|
| 92 | Cupronickel 55–45 (Constantan) | Cu 55.0 Ni 45.0 | Annealed<br>Cold-drawn<br>Cold-rolled | 30<br>50<br>65 | 60<br>65<br>85 | 45<br>30<br>20 | —<br>—<br>— | Electrical-resistance wire; low temperature coefficient, high resistivity |
| 93 | Nichrome | Ni 80.0 Cr 20.0 | | | | | | Heating elements for furnaces |
| 94 | "S" Monel | Ni 60.0 Cu 29.0<br>Fe 2.50 max Mn 1.5 max<br>Si 4.0 Al 0.5 max | Sand-casting | 80–115 | 110–145 | 2 | 270–350 | High-strength casting alloy; good bearing properties for valve seats |
| | **TITANIUM ALLOYS** | | | | | | | |
| | The main application for these alloys is in the aerospace industry. Because of the low density and high strength of titanium alloys, they present excellent strength-to-weight ratios. | | | | | | | |
| 95 | Commercial titanium ASTM B265–58T | Ti 99.4 | Annealed at 1100 to 1350°F (593 to 732°C) | 70 | 80 | 20 | — | Moderate strength, excellent fabricability; chemical industry pipes |
| 96 | Titanium alloy ASTM B265–58T–5 Ti–6 Al–4V | | Water-quenched from 1750°F (954°C); aged at 1000°F (538°C) for 2 hr | 160 | 170 | 13 | — | High-temperature strength needed in gas-turbine compressor blades |
| 97 | Titanium alloy Ti–4 Al–4Mn | | Water-quenched from 1450°F (788°C); aged at 900°F (482°C) for 8 hr | 170 | 185 | 13 | — | Aircraft forgings and compressor parts |
| 98 | Ti–Mn alloy ASTM B265–58T–7 | Fe 0.5 Ti bal.<br>Mn 7.0–8.0 | Sheet | 140 | 150 | 18 | — | Good formability, moderate high-temperature strength; aircraft skin |
| | **ZINC ALLOYS** | | | | | | | |
| | A major use for these alloys is for low-cost die-cast products, such as household fixtures, automotive parts, and trim. | | | | | | | |
| 99 | Zinc ASTM B69 | Cd 0.35 Zn bal.<br>Pb 0.08 | Hot-rolled | — | 19.5 | 65 | 38 | Battery cans, grommets, lithographer's sheet |



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**TABLE C.5 (continued) Mechanical Properties of Metals and Alloys:* Typical Composition, Properties, and Uses of Common Materials**

| *No.* | *Material* | *Nominal composition* | *Form and condition* | *Typical mechanical properties* | | | | *Comments* |
|---|---|---|---|---|---|---|---|---|
| | | | | *Yield strength (0.2% offset), 1000 lb/sq in.* | *Tensile strength, 1000 lb/sq in.* | *Elongation, in 2 in., %* | *Hardness, Brinell* | |
| 100 | Zilloy-15 | Cu 1.00 Zn bal.<br>Mg 0.010 | Hot-rolled<br>Cold-rolled | —<br>— | 29<br>36 | 20<br>25 | 61<br>80 | Corrugated roofs, articles with maximum stiffness |
| 101 | Zilloy-40 | Cu 1.00 Zn bal. | Hot-rolled<br>Cold-rolled | —<br>— | 24<br>31 | 50<br>40 | 52<br>60 | Weatherstrip, spun articles |
| 102 | Zamac-5<br>ASTM 25 | Zn (99.99% pure remainder) Al 3.5–4.3 Cu 0.75–1.25 Mg 0.03–0.08 | Die-cast | — | 47.6 | 7 | 91 | Die casting for automobile parts, padlocks; used also for die material |
| | | **ZIRCONIUM ALLOYS** | | | | | | |
| | | These alloys have good corrosion resistance but are easily oxidized at elevated temperatures in air. The major application is for use in nuclear reactors. | | | | | | |
| 103 | Zirconium, commercial | $O_2$ 0.07 C 0.15<br>Hf 1.90 Zr bal. | Annealed | 40 | 65 | 27 | B80 (Rockwell) | |
| 104 | Zircaloy 2 | Hf 0.02 Ni 0.05<br>Fe 0.15 Other 0.25<br>Sn 1.46 Zr bal. | Annealed | 50 | 75 | 22 | B90 (Rockwell) | Nuclear power-reactor cores at elevated temperatures |

*Compiled from various sources.



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**TABLE C.6 Miscellaneous Properties of Metals and Alloys**

## Part a. Pure Metals

**At Room Temperature**

| *Common name* | *PROPERTIES (TYPICAL ONLY)* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Thermal conductivity, Btu/hr ft °F* | *Specific gravity* | *Coeff. of linear expansion, μ in./ in. °F* | *Electrical resistivity, microhm-cm* | *Poisson's ratio* | *Modulus of elasticity, millions of psi* | *Approximate melting point, °F* |
| Aluminum | 137 | 2.70 | 14 | 2.655 | 0.33 | 10.0 | 1220 |
| Antimony | 10.7 | 6.69 | 5 | 41.8 | | 11.3 | 1170 |
| Beryllium | 126 | 1.85 | 6.7 | 4.0 | 0.024–.030 | 42 | 2345 |
| Bismuth | 4.9 | 9.75 | 7.2 | 115 | | 4.6 | 521 |
| Cadmium | 54 | 8.65 | 17 | 7.4 | | 8 | 610 |
| Chromium | 52 | 7.2 | 3.3 | 13 | | 36 | 3380 |
| Cobalt | 40 | 8.9 | 6.7 | 9 | | 30 | 2723 |
| Copper | 230 | 8.96 | 9.2 | 1.673 | 0.36 | 17 | 1983 |
| Gold | 182 | 19.32 | 7.9 | 2.35 | 0.42 | 10.8 | 1945 |
| Iridium | 85.0 | 22.42 | 3.3 | 5.3 | | 75 | 4440 |
| Iron | 46.4 | 7.87 | 6.7 | 9.7 | | 28.5 | 2797 |
| Lead | 20.0 | 11.35 | 16 | 20.6 | 0.40–.45 | 2.0 | 621 |
| Magnesium | 91.9 | 1.74 | 14 | 4.45 | 0.35 | 6.4 | 1200 |
| Manganese | | 7.21–7.44 | 12 | 185 | | 23 | 2271 |
| Mercury | 4.85 | 13.546 | | 98.4 | | | −38 |
| Molybdenum | 81 | 10.22 | 3.0 | 5.2 | 0.32 | 40 | 4750 |
| Nickel | 52.0 | 8.90 | 7.4 | 6.85 | 0.31 | 31 | 2647 |
| Niobium (Columbium) | 30 | 8.57 | 3.9 | 13 | | 15 | 4473 |
| Osmium | 35 | 22.57 | 2.8 | 9 | | 80 | 5477 |
| Platinum | 42 | 21.45 | 5 | 10.5 | 0.39 | 21.3 | 3220 |
| Plutonium | 4.6 | 19.84 | 30 | 141.4 | 0.15–.21 | 14 | 1180 |
| Potassium | 57.8 | 0.86 | 46 | 7.01 | | | 146 |
| Rhodium | 86.7 | 12.41 | 4.4 | 4.6 | | 42 | 3569 |
| Selenium | 0.3 | 4.8 | 21 | 12.0 | | 8.4 | 423 |
| Silicon | 48.3 | 2.33 | 2.8 | $1 \times 10^5$ | | 16 | 2572 |
| Silver | 247 | 10.50 | 11 | 1.59 | 0.37 | 10.5 | 1760 |
| Sodium | 77.5 | 0.97 | 39 | 4.2 | | | 208 |
| Tantalum | 31 | 16.6 | 3.6 | 12.4 | 0.35 | 27 | 5400 |
| Thorium | 24 | 11.7 | 6.7 | 18 | 0.27 | 8.5 | 3180 |
| Tin | 37 | 7.31 | 11 | 11.0 | 0.33 | 6 | 450 |
| Titanium | 12 | 4.54 | 4.7 | 43 | 0.3 | 16 | 3040 |
| Tungsten | 103 | 19.3 | 2.5 | 5.65 | 0.28 | 50 | 6150 |
| Uranium | 14 | 18.8 | 7.4 | 30 | 0.21 | 24 | 2070 |
| Vanadium | 35 | 6.1 | 4.4 | 25 | | 19 | 3450 |
| Zinc | 66.5 | 7 | 19 | 5.92 | 0.25 | 12 | 787 |

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**TABLE C.6 Miscellaneous Properties of Metals and Alloys**

## Part b. Commercial Metals and Alloys

| *CLASSIFICATION AND DESIGNATION* | | *PROPERTIES (TYPICAL ONLY)* | | | | | |
|---|---|---|---|---|---|---|---|
| *Material No. (from Table 1-57)* | *Common name and classification* | *Thermal conductivity, Btu/hr ft °F* | *Specific gravity* | *Coeff. of linear expansion, μ in./ in. °F* | *Electrical resistivity, microhm-cm* | *Modulus of elasticity, millions of psi* | *Approximate melting point, °F* |
| 1 | Ingot iron (included for comparison) | 42. | 7.86 | 6.8 | 9. | 30 | 2800 |
| 2 | Plain carbon steel AISI–SAE 1020 | 30. | 7.86 | 6.7 | 10. | 30 | 2760 |
| 15 | Stainless steel type 304 | 10. | 8.02 | 9.6 | 72. | 28 | 2600 |
| 19 | Cast gray iron ASTM A48-48, Class 25 | 26. | 7.2 | 6.7 | 67. | 13 | 2150 |
| 21 | Malleable iron ASTM A47 | — | 7.32 | 6.6 | 30. | 25 | 2250 |
| 22 | Ductile cast iron ASTM A339, A395 | 19 | 7.2 | 7.5 | 60. | 25 | 2100 |
| 24 | Ni-resist cast iron, type 2 | 23 | 7.3 | 9.6 | 170. | 15.6 | 2250 |
| 29 | Cast 28–7 alloy (HD) ASTM A297-63T | 1.5 | 7.6 | 9.2 | 41. | 27 | 2700 |
| 31 | Hastelloy C | 5 | 3.94 | 6.3 | 139. | 30 | 2350 |
| 36 | Inconel X, annealed | 9 | 8.25 | 6.7 | 122. | 31 | 2550 |
| 41 | Haynes Stellite alloy 25 (L605) | 5.5 | 9.15 | 7.61 | 88. | 34 | 2500 |
| 43 | Aluminum alloy 3003, rolled ASTM B221 | 90 | 2.73 | 12.9 | 4. | 10 | 1200 |
| 44 | Aluminum alloy 2017, annealed ASTM B221 | 95 | 2.8 | 12.7 | 4. | 10.5 | 1185 |
| 49 | Aluminum alloy 380 ASTM SC84B | 56 | 2.7 | 11.6 | 7.5 | 10.3 | 1050 |
| 53 | Copper ASTM B152, B124, B133, B1, B2, B3 | 225 | 8.91 | 9.3 | 1.7 | 17 | 1980 |
| 57 | Yellow brass (high brass) ASTM B36, B134, B135 | 69 | 8.47 | 10.5 | 7. | 15 | 1710 |
| 61 | Aluminum bronze ASTM B169, alloy A; ASTM B124, B150 | 41 | 7.8 | 9.2 | 12. | 17 | 1900 |
| 62 | Beryllium copper 25 ASTM B194 | 7 | 8.25 | 9.3 | — | 19 | 1700 |
| 64 | Nickel silver 18% alloy A (wrought) ASTM B122, No. 2 | 19 | 8.8 | 9.0 | 29. | 18 | 2030 |
| 67 | Cupronickel 30% | 17 | 8.95 | 8.5 | 35. | 22 | 2240 |
| 68 | Red brass (cast) ASTM B30, No. 4A | 42 | 8.7 | 10. | 11. | 13 | 1825 |
| 74 | Chemical lead | 20 | 11.35 | 16.4 | 21. | 2 | 621 |
| 75 | Antimonial lead (hard lead) | 17 | 10.9 | 15.1 | 23. | 3 | 554 |
| 80 | Solder 50–50 | 26 | 8.89 | 13.1 | 15. | — | 420 |
| 82 | Magnesium alloy AZ31B | 45 | 1.77 | 14.5 | 9. | 6.5 | 1160 |
| 89 | K Monel | 11 | 8.47 | 7.4 | 58. | 26 | 2430 |
| 90 | Nickel ASTM B160, B161, B162 | 35 | 8.89 | 6.6 | 10. | 30 | 2625 |
| 92 | Cupronickel 55–45 (Constantan) | 13 | 8.9 | 8.1 | 49. | 24 | 2300 |
| 95 | Commercial titanium | 10 | 5. | 4.9 | 80. | 16.5 | 3300 |
| 99 | Zinc ASTM B69 | 62 | 7.14 | 18 | 6. | — | 785 |
| 103 | Zirconium, commercial | 10 | 6.5 | 2.9 | 41. | 12 | 3350 |

*Compiled from several sources.

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**TABLE C.7 Composition and Melting Points of Binary Eutectic Alloys:* Binary Alloys and Solid Solutions of Metallic Components**

This table represents most of the common binary combinations of metals. For many pairs no eutectic exists; for many others the information is uncertain or unavailable. In a fair number of cases, there is complete mutual solubility in all proportions; hence, there is a smooth temperature vs. composition curve, with no point of inflection from the melting point of one constituent to that of the other. For purposes of comparison, all values must be considered approximate in view of the experimental difficulties and the many sources of data.

Those pairs for which the liquidus curve exhibits more than one cusp are designated by a superscript *a*. In a few cases the cusp selected for this table does not represent the lowest possible melting point for the binary mixture.

| *Constituents* | | *Composition* | | *Melting point* | | *Constituents* | | *Composition* | | *Melting point* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *A* | *B* | *Mol % B* | *Weight % B* | *K* | *deg F* | *A* | *B* | *Mol % B* | *Weight % B* | *K* | *deg F* |
| Ag | Al | 57 | 25 | 835 | 1 044 | Au | Bi | 86.8 | 85 | 514 | 466 |
| Ag | As | 24 | 18 | 813 | 1 004 | Au | Cd | 70 | 57.1 | 773 | 932 |
| Ag | Ca[a] | 37 | 18 | 820 | 1 017 | Au | Ce[a] | 86 | 81 | 793 | 968 |
| Ag | Ce[a] | 80 | 84 | 798 | 977 | Au | Ge | 27 | 12 | 629 | 673 |
| Ag | Cu | 40 | 28 | 1 050 | 1 431 | Au | La[a] | 83 | 78 | 834 | 1 042 |
| Ag | Ge | 25 | 18 | 924 | 1 204 | Au | Mg | 93 | 62 | 848 | 1 067 |
| Ag | La[a] | 72 | 77 | 791 | 964 | Au | Mn[a] | 32 | 12 | 1 233 | 1 760 |
| Ag | Li | 99 | 89 | 418 | 293 | Au | Na | 17 | 2.3 | 1 149 | 1 609 |
| Ag | Mg[a] | 83 | 52 | 745 | 882 | Au | Pb | 84 | 85 | 488 | 419 |
| Ag | Pb | 95.3 | 97.5 | 577 | 579 | Au | Sb | 34.8 | 24.8 | 633 | 680 |
| Ag | Pd | 25.9 | 25.6 | 924 | 1 204 | Au | Si | 18.6 | 3.15 | 636 | 685 |
| Ag | Sb | 41 | 44 | 758 | 905 | Au | Sn[a] | 29.3 | 19.9 | 551 | 532 |
| Ag | Si | 10.5 | 2.96 | 1 110 | 1 539 | Au | Te | 88 | 83 | 689 | 781 |
| Ag | Sr[a] | 77 | 73 | 709 | 817 | Au | Tl | 72 | 73 | 404 | 268 |
| Ag | Te | 65 | 69 | 623 | 662 | Au | U | 14 | 16 | 1 128 | 1 571 |
| Ag | Th | 7.6 | 15 | 1 167 | 1 641 | B | Hf | 13 | 71 | 2 130 | 3 375 |
| Ag | Zr | 97 | 93 | 1 100 | 1 521 | B | Ni | 57 | 88 | 1 263 | 1 814 |
| Al | Au[a] | 59,5 | 90.0 | 842 | 1 056 | B | Ti | 7 | 25 | 1 700 | 2 601 |
| Al | Ca[a] | 65 | 73 | 818 | 1 013 | B | Zr | 88 | 98 | 1 920 | 2 997 |
| Al | Cd | 81 | 90 | 1 650 | 2 511 | Ba | Mg | 97 | 87 | 891 | 1 144 |
| Al | Ce | 69 | 92 | 928 | 1 211 | Be | Ni | 33 | 76 | 1 468 | 2 183 |
| Al | Cu[a] | 17.3 | 33.0 | 821 | 1 018 | Be | Pu | 97 | 99 | 910 | 1 179 |
| Al | Fe | 32 | 49.34 | 1 426 | 2 107 | Be | Si | 33 | 61 | 1 363 | 1 994 |
| Al | Ge | 29 | 55 | 700 | 801 | Be | Ti | 75 | 94 | 1 300 | 2 061 |
| Al | In | 5 | 18 | 910 | 1 179 | Be | Y | 61 | 94 | 1 390 | 2 043 |
| Al | Mg | 70 | 67.0 | 710 | 819 | Be | Zr | 65 | 95 | 1 250 | 1 791 |
| Al | Ni[a] | 76 | 87 | 1 658 | 2 525 | Bi | Ca | 88 | 58.5 | 1 059 | 1 447 |
| Al | Pt[a] | 57 | 90 | 1 533 | 2 300 | Bi | Cd | 56 | 40 | 420 | 297 |
| Al | Si | 13 | 13 | 850 | 1 071 | Bi | In[a] | 78 | 66 | 340 | 153 |
| Al | Th | 80 | 97 | 1 510 | 2 259 | Bi | K | 50 | 16 | 615 | 648 |
| Al | Zn | 88.7 | 95.0 | 655 | 720 | Bi | Mg | 85 | 40 | 820 | 1 017 |
| As | Co | 75 | 70 | 1 189 | 1 681 | Bi | Na | 22 | 3.0 | 500 | 441 |
| As | Cu[a] | 81.6 | 78.0 | 958 | 1 265 | Bi | Pb | 44 | 44 | 397 | 255 |
| As | Fe | 75 | 69 | 1 103 | 2 017 | Bi | Sn | 57 | 43 | 415 | 288 |
| As | In | 13 | 18 | 1 004 | 1 348 | Bi | Te | 90 | 84 | 686 | 775 |
| As | Mn | 57 | 49 | 1 143 | 1 598 | Bi | Tl[a] | 53 | 52 | 465 | 378 |
| As | Ni[a] | 63 | 57 | 1 077 | 1 479 | C | Cr | 87 | 96 | 1 775 | 2 736 |
| As | Sb | 80 | 87 | 878 | 1 121 | C | Hf | 35 | 88 | 3 450 | 5 751 |
| As | Sn[a] | 40 | 51 | 852 | 1 074 | C | Mo | 17 | 45 | 2 480 | 4 005 |
| As | Zn[a] | 20 | 18 | 996 | 1 333 | C | Nb | 40 | 84 | 3 580 | 5 985 |

*Compiled from several sources.

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**TABLE C.7 (continued) Composition and Melting Points of Binary Eutectic Alloys:* Binary Alloys and Solid Solutions of Metallic Components**

| *Constituents* | | *Composition* | | *Melting point* | | *Constituents* | | *Composition* | | *Melting point* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *A* | *B* | *Mol % B* | *Weight % B* | *K* | *deg F* | *A* | *B* | *Mol % B* | *Weight % B* | *K* | *deg F* |
| C | Ti | 36 | 69 | 3 050 | 5 031 | Gd | Ni[a] | 32 | 15 | 943 | 1 238 |
| C | V | 84 | 96 | 1 900 | 2 961 | Ge | Mg | 38 | 17 | 953 | 1 256 |
| C | W | 59 | 96 | 2 980 | 4 905 | Ge | Mn[a] | 48 | 41 | 970 | 1 287 |
| Ca | Cu | 51 | 62 | 833 | 1 040 | Hf | Ta | 24 | 24 | 1 300 | 1 881 |
| Ca | Mg[a] | 32 | 22 | 718 | 833 | In | Ni | 30 | 17.97 | 1 143 | 1 598 |
| Ca | Na | 22 | 14 | 983 | 1 310 | In | Sb | 68 | 69 | 780 | 945 |
| Ca | Ni | 16 | 22 | 878 | 1 121 | In | Sn | 47 | 48 | 390 | 243 |
| Ca | Sn | 19 | 41 | 1 010 | 1 359 | Ir | Mo | 68 | 52 | 2 350 | 3 771 |
| Cd | Cu | 52 | 38 | 810 | 999 | Ir | Nb | 55 | 23 | 2 110 | 3 339 |
| Cd | In | 74 | 74 | 400 | 261 | Ir | W | 22 | 12 | 2 590 | 4 203 |
| Cd | Pb | 71 | 82 | 540 | 513 | K | Na | 32 | 21.67 | 260 | −8.6 |
| Cd | Pu | 40 | 59 | 1 170 | 1 647 | K | Rb | 70 | 84 | 307 | 93 |
| Cd | Sb | 7.4 | 8 | 563 | 554 | K | Sb[a] | 68 | 84 | 680 | 765 |
| Cd | Sn | 68 | 69 | 450 | 351 | K | Tl | 84 | 96 | 440 | 333 |
| Cd | Tl | 73 | 83 | 475 | 396 | La | Mg[a] | 38 | 9.7 | 970 | 1 287 |
| Cd | Zn | 27 | 18 | 540 | 513 | La | Pb[a] | 11 | 15 | 1 049 | 1 429 |
| Ce | Cu[a] | 28 | 15 | 688 | 779 | La | Sn[a] | 10 | 9 | 993 | 1 328 |
| Ce | Ru | 33 | 26 | 923 | 1 202 | La | Tl | 16 | 22 | 913 | 1 184 |
| Co | Gd | 65 | 83 | 913 | 1 184 | Mg | Ni | 11 | 22.98 | 780 | 945 |
| Co | Mo | 27 | 38 | 1 610 | 2 439 | Mg | Pr | 4.9 | 23 | 858 | 1 085 |
| Co | Nb | 15 | 22 | 1 500 | 2 241 | Mg | Pu | 15 | 63 | 815 | 1 008 |
| Co | Si[a] | 71 | 54 | 1 486 | 2 215 | Mg | Sb[a] | 86 | 97 | 855 | 1 080 |
| Co | Sn | 21 | 35 | 1 380 | 2 025 | Mg | Si | 53 | 57 | 1 223 | 1 742 |
| Co | Ti[a] | 22 | 19 | 1 430 | 2 115 | Mg | Sr[a] | 70 | 89 | 699 | 799 |
| Co | V | 41 | 38 | 1 521 | 2 278 | Mg | Th | 7 | 42 | 855 | 1 080 |
| Cr | Mo | 14 | 23 | 1 973 | 3 092 | Mg | Zn | 30 | 53 | 615 | 648 |
| Cr | Ni | 46 | 47 | 1 610 | 2 439 | Mn | Ni | 40 | 42 | 1 300 | 1 881 |
| Cr | Ta | 13 | 34 | 1 950 | 3 051 | Mn | Pd | 26 | 41 | 1 398 | 2 057 |
| Cr | Ti | 86 | 85 | 950 | 1 251 | Mn | Sb | 82 | 91 | 843 | 1 058 |
| Cr | V | 33 | 32 | 2 050 | 3 231 | Mn | Ti[a] | 9 | 7.9 | 1 460 | 2 169 |
| Cs | K | 50 | 23 | 235 | −36 | Mn | U[a] | 75 | 93 | 988 | 1 319 |
| Cs | Na | 20.9 | 4.37 | 241 | −26 | Mn | Y[a] | 65 | 75 | 1 163 | 1 634 |
| Cs | Rb | 50 | 39 | 282 | 48 | Mo | Nb | 66 | 65 | 2 570 | 4 167 |
| Cu | Ge | 34 | 37 | 913 | 1 184 | Mo | Ni | 64 | 52 | 1 590 | 2 403 |
| Cu | Mg[a] | 85.5 | 69.3 | 758 | 905 | Mo | Os | 21 | 34 | 2 650 | 4 311 |
| Cu | Mn | 37 | 34 | 1 143 | 1 598 | Mo | Pd | 54 | 57 | 2 020 | 3 177 |
| Cu | Pb | 15 | 36 | 1 230 | 1 755 | Mo | Re | 48 | 64 | 2 780 | 4 545 |
| Cu | Pr[a] | 69 | 83 | 745 | 882 | Mo | Ru | 41 | 42 | 2 200 | 3 501 |
| Cu | Sb[a] | 63 | 76 | 800 | 981 | Mo | Si[a] | 17 | 5.7 | 2 350 | 3 771 |
| Cu | Si | 30 | 16 | 1 075 | 1 476 | Na | Rb | 82.1 | 94.5 | 269 | 25 |
| Cu | Te | 69 | 82 | 617 | 207 | Na | Sb | 60 | 89 | 678 | 761 |
| Cu | Ti[a] | 27 | 22 | 1 133 | 1 580 | Na | Sn | 37 | 75 | 718 | 833 |
| Cu | Tl | 14.5 | 35.3 | 1 357 | 1 983 | Na | Te | 55 | 87 | 592 | 606 |
| Cu | U | 8.2 | 25 | 1 213 | 1 724 | Nb | Ni | 58 | 47 | 1 450 | 2 151 |
| Cu | Zr | 9.4 | 13 | 1 253 | 1 796 | Nb | Pt | 54 | 71 | 1 970 | 3 087 |
| Fe | Gd | 69 | 86 | 1 123 | 1 562 | Nb | Rh | 45 | 31 | 1 770 | 2 727 |
| Fe | Mo | 21 | 31 | 1 725 | 2 646 | Nb | Ru[a] | 64 | 49 | 2 050 | 3 231 |
| Fe | Nb | 12 | 18.49 | 1 643 | 2 498 | Nb | Zr | 77 | 77 | 2 010 | 3 159 |
| Fe | Sb | 88 | 94.10 | 1 021 | 1 378 | Ni | Sb | 22 | 36.90 | 1 375 | 2 016 |
| Fe | Si[a] | 35 | 21 | 1 475 | 2 196 | Ni | Sn | 19 | 32.16 | 1 403 | 2 066 |
| Fe | Sn | 31 | 49 | 1 400 | 2 061 | Ni | Th[a] | 35 | 68 | 1 303 | 1 886 |
| Fe | Y | 65 | 75 | 1 173 | 1 652 | Ni | Ti[a] | 39 | 34 | 1 390 | 2 043 |
| Fe | Zr[a] | 11 | 17 | 1 600 | 2 421 | Ni | V | 52 | 48 | 1 473 | 2 192 |
| Ga | Mg[a] | 80 | 58 | 698 | 797 | Ni | W | 20.7 | 45 | 1 773 | 2 732 |
| Ga | Ni | 70 | 66 | 1 477 | 2 199 | Ni | Zn | 69 | 71 | 1 148 | 1 607 |

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**TABLE C.7 (continued) Composition and Melting Points of Binary Eutectic Alloys:* Binary Alloys and Solid Solutions of Metallic Components**

| *Constituents* | | *Composition* | | *Melting point* | | *Constituents* | | *Composition* | | *Melting point* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *A* | *B* | *Mol % B* | *Weight % B* | *K* | *deg F* | *A* | *B* | *Mol % B* | *Weight % B* | *K* | *deg F* |
| Pb | Pr | 40 | 31 | 1 315 | 1 908 | Si | Th[a] | 88 | 98 | 1 710 | 2 619 |
| Pb | Pt | 5.3 | 5.0 | 563 | 554 | Si | Ti[a] | 86 | 91 | 1 600 | 2 421 |
| Pb | Sb | 18 | 11 | 520 | 477 | Si | Zr[a] | 9 | 24 | 1 570 | 2 367 |
| Pb | Sn | 73 | 61 | 460 | 369 | Sn | Te | 84 | 85 | 678 | 761 |
| Pb | Te | 85 | 78 | 680 | 765 | Sn | Tl | 31 | 44 | 440 | 333 |
| Pb | Ti | 92 | 74 | 998 | 1 337 | Sn | Zn | 16 | 9.5 | 465 | 378 |
| Pd | Sb | 89 | 90 | 868 | 1 103 | Te | Tl | 30 | 41 | 483 | 410 |
| Pt | Sn | 40 | 29 | 1 345 | 1 962 | Th | Ti | 40 | 12 | 1 463 | 2 174 |
| Pu | Zn | 73 | 42 | 1 100 | 1 521 | Th | Zn[a] | 49 | 21 | 1 220 | 1 737 |
| Re | W | 26 | 26 | 3 100 | 5 121 | Ti | U | 17 | 51 | 933 | 1 220 |
| Sb | Tl | 70 | 80 | 468 | 383 | Ti | Y | 6.8 | 12 | 1 593 | 2 408 |
| Sb | Zn | 33 | 21 | 780 | 945 | Ti | Zr | 50 | 66 | 790 | 963 |
| Sb | Zr | 82 | 77 | 1 700 | 2 601 | U | Zr | 70 | 47 | 879 | 1 123 |
| Se | Sn | 39 | 49 | 913 | 1 184 | | | | | | |
| Se | Tl | 26 | 48 | 424 | 304 | | | | | | |

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See also *Trans. AIME*, *J. Inst. Metals*, and *Z. Metallkunde*, by indexes.

**TABLE C.8 Melting Points of Mixtures of Metals****

**Melting Points, °C**

| *Metals* | *Percentage of metal in second column* | | | | | | | | | | | *Metals* | *Percentage of metal in second column* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% | | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| | * | | | | | | | | | | | | * | | | | | | | | | | |
| Pb. Sn. | 326 | 295 | 276 | 262 | 240 | 220 | 190 | 185 | 200 | 216 | 232 | Ni. Sn. | 1455 | 1380 | 1290 | 1200 | 1235 | 1290 | 1305 | 1230 | 1060 | 800 | 232 |
| Bi. | 322 | 290 | ... | ... | 179 | 145 | 126 | 168 | 205 | ... | 268 | Na. Bi. | 96 | 425 | 520 | 590 | 645 | 690 | 720 | 730 | 715 | 570 | 268 |
| Te. | 322 | 710 | 790 | 880 | 917 | 760 | 600 | 480 | 410 | 425 | 446 | Cd. | 96 | 125 | 185 | 245 | 285 | 325 | 330 | 340 | 360 | 390 | 322 |
| Ag. | 328 | 460 | 545 | 590 | 620 | 650 | 705 | 775 | 840 | 905 | 959 | Cd. Ag. | 322 | 420 | 520 | 610 | 700 | 760 | 805 | 850 | 895 | 940 | 954 |
| Na. | ... | 360 | 420 | 400 | 370 | 330 | 290 | 250 | 200 | 130 | 96 | Tl. | 321 | 300 | 285 | 270 | 262 | 258 | 245 | 230 | 210 | 235 | 302 |
| Cu. | 326 | 870 | 920 | 925 | 945 | 950 | 955 | 985 | 1005 | 1020 | 1084 | Zn. | 322 | 280 | 270 | 295 | 313 | 327 | 340 | 355 | 370 | 390 | 419 |
| Sb. | 326 | 250 | 275 | 330 | 395 | 440 | 490 | 525 | 560 | 600 | 632 | Au. Cu. | 1063 | 910 | 890 | 895 | 905 | 925 | 975 | 1000 | 1025 | 1060 | 1084 |
| Al. Sb. | 650 | 750 | 840 | 925 | 945 | 950 | 970 | 1000 | 1040 | 1010 | 632 | Ag. | 1064 | 1062 | 1061 | 1058 | 1054 | 1049 | 1039 | 1025 | 1006 | 982 | 963 |
| Cu. | 650 | 630 | 600 | 560 | 540 | 580 | 610 | 755 | 930 | 1055 | 1084 | Pt. | 1075 | 1125 | 1190 | 1250 | 1320 | 1380 | 1455 | 1530 | 1610 | 1685 | 1775 |
| Au. | 655 | 675 | 740 | 800 | 855 | 915 | 970 | 1025 | 1055 | 675 | 1062 | K. Na. | 62 | 17.5 | −10 | −3.5 | 5 | 11 | 26 | 41 | 58 | 77 | 97.5 |
| Ag. | 650 | 625 | 615 | 600 | 590 | 580 | 575 | 570 | 650 | 750 | 954 | Hg. | ... | ... | ... | ... | ... | 90 | 110 | 135 | 162 | 265 | ... |
| Zn. | 654 | 640 | 620 | 600 | 580 | 560 | 530 | 510 | 475 | 425 | 419 | Tl. | 62.5 | 133 | 165 | 188 | 205 | 215 | 220 | 240 | 280 | 305 | 301 |
| Fe. | 653 | 860 | 1015 | 1110 | 1145 | 1145 | 1220 | 1315 | 1425 | 1500 | 1515 | Cu. Ni. | 1080 | 1180 | 1240 | 1290 | 1320 | 1355 | 1380 | 1410 | 1430 | 1440 | 1455 |
| Sn. | 650 | 645 | 635 | 625 | 620 | 605 | 590 | 570 | 560 | 540 | 232 | Ag. | 1082 | 1035 | 990 | 945 | 910 | 870 | 830 | 788 | 814 | 875 | 960 |
| Sb. Bi. | 632 | 610 | 590 | 575 | 555 | 540 | 520 | 470 | 405 | 330 | 268 | Sn. | 1084 | 1005 | 890 | 755 | 725 | 680 | 630 | 580 | 530 | 440 | 232 |
| Ag. | 630 | 595 | 570 | 545 | 520 | 500 | 505 | 545 | 680 | 850 | 959 | Zn. | 1084 | 1040 | 995 | 930 | 900 | 880 | 820 | 780 | 700 | 580 | 419 |
| Sn. | 622 | 600 | 570 | 525 | 480 | 430 | 395 | 350 | 310 | 255 | 232 | Ag. Zn. | 959 | 850 | 755 | 705 | 690 | 660 | 630 | 610 | 570 | 505 | 419 |
| Zn. | 632 | 555 | 510 | 540 | 570 | 565 | 540 | 525 | 510 | 470 | 419 | Sn. | 959 | 870 | 750 | 630 | 550 | 495 | 450 | 420 | 375 | 300 | 232 |
| | | | | | | | | | | | | Na. Hg. | 96.5 | 90 | 80 | 70 | 60 | 45 | 22 | 55 | 95 | 215 | ... |

*The data in this table are compiled from various sources—hence the variations in the melting point of the metals as shown in this column.

**Based largely on: "Smithsonian Physical Tables", 9th rev. ed., W.E. Forsythe, Ed., The Smithsonian Institution, 1956.

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## TABLE C.9 Trade Names, Composition, and Manufacturers of Various Plastics

| *Trade name* | *Composition* | *Manufacturer* |
|---|---|---|
| Abson | Acrylonitrile-butadiene, ABS polymers | B. F. Goodrich Chemical Co. |
| Alathon | Polyethylene resins | E. I. du Pont de Nemours & Co., Inc. |
| Alkor | Furane resin cement | Atlas Minerals & Chemicals Div., The Electric Storage Battery Co. |
| Amres | Phenolics, urea, and melamine resins | American Marietta Co., Pacific Resins & Chemicals, Inc. |
| Araldite | Epoxy resins | CIBA Products Co., Div. CIBA Corp. |
| Atlac | Polyester resins | Atlas Chemical Industries, Inc. |
| Bakelite | Acrylics, epoxies, phenolics, polyethylenes, copolymers | Union Carbide Corp., Chemicals and Plastics Div. |
| Bavick-11 | Methyl methacrylate and methylstyrene copolymer | J. T. Baker Chemical Co. |
| Boltaflex | Supported and unsupported flexible vinyl sheeting | The General Tire & Rubber Co. |
| Boltaron | Rigid polyvinyl chloride sheet | The General Tire & Rubber Co., Chemical & Plastics Div. |
| Butacite | Polyvinyl butyral resins | E. I. du Pont de Nemours & Co., Inc. |
| Conolite | Polyester resins and laminates | Shellmar-Betner, Div. Continental Can Co.<br>Woodall Industries, Inc., Conolite Div. |
| Corvel | Epoxies, vinyls<br>Fusion-bond finishes | The Polymer Corp., Export-Polypenco Div. |
| Cumar | Paracoumarone-indene resins | Allied Chemical Corp., Plastics Div. |
| Cycolac | ABS polymers, acrylonitrile-butadiene-styrene copolymers | Marbon Chemical Div., Borg-Warner Corporation |
| Dacovin | Polyvinyl chlorides | Diamond Shamrock Corp. |
| Dapon | Diallyl phthalate resins | FMC Corp., Organic Div. |
| Delrin | Acetal resin and pipe | E. I. du Pont de Nemours & Co., Inc. |
| Dylan | Polyethylene | Sinclair-Koppers Co. |
| Dylene | Polystyrene | Sinclair-Koppers Co. |
| Dylite | Expandable polystyrene | Sinclair-Koppers Co. |
| Epi-Rez | Epoxy resins | Celanese Coatings Co., Celanese Resin Div. |
| Epolene | Low molecular-weight polyethylene resins | Eastman Chemical Products, Inc., Sub. Eastman Kodak Company |
| Epoxical | Epoxy resins | United States Gypsum Co. |
| Epon | Epoxy resins and curing agents | The Shell Chemical Company, Plastics and Resins Div. |
| Escon | Polypropylene resins | Enjay Chemical Co., Div. Humble Oil & Refining Company |
| Estane | Polyurethane materials | B. F. Goodrich Chemical Company |
| Fluorogreen | Teflon with glass and ceramic fibers, fluorocarbons | John L. Dore Co. |
| Fluororay | Ceramic-filled fluorocarbons | Raybestos-Manhattan, Inc., Plastic Products Div. |
| Formica | Melamines | Formica Corp. of American Cyanamid |
| Forticel | Cellulose propionate sheet films, molding powders | Celanese Plastics Co. |
| Fortiflex | Polyethylene resins | Celanese Plastics Co. |
| Fosta-Tuf-Flex | Polystyrene, high-impact | Foster-Grant, Inc. |
| Furnane | Furanes | Atlas Minerals & Chemicals Div., The Electric Storage Battery Co. |
| GenEpoxy | Epoxy resins for adhesives, coatings, etc. | General Mills, Inc., Chemical Div. |
| Genetron | Fluorinated hydrocarbons, monomers, and polymers | Allied Chemical Corp., General Chemical Div. |
| Geon | Polyvinyl chloride materials | B. F. Goodrich Chemical Co. |
| Grex | High-density polyethylenes | Allied Chemical Corp., Plastics Div. |
| Halon | Fluorohalocarbon resins | Allied Chemical Corp. |
| Hetron | Fire-retardant polyester resin | Hooker Chemical Corp., Durez Plastics Div. |
| Isothane | Polyurethane foam, ester, and ether | Bernel Foam Products Co., Inc. |
| Kel-F | Chlorotrifluoroethylene, molding resins, and dispersions | 3M Company |
| Kralac | High-styrene resins, styrene-butadiene copolymers | Uniroyal Chemical, Div. of Uniroyal Inc. |
| Kralastic | ABS polymers, copolymers | Uniroyal Chemical, Div. of Uniroyal Inc. |
| Kynar | Polyvinylidene fluoride | Pennsalt Chemical Corp. |
| Lexan | Polycarbonate resin, film, and sheet | General Electric Company, Plastics Dept. |
| Lucite | Acrylic resin and syrup | E. I. du Pont de Nemours & Co., Inc. |
| Lustran | ABS polymers | Monsanto Co. |
| Lustrex | Styrene molding and extrusion resins | Monsanto Co. |
| Lytron | Styrene molding and extrusion resins | Monsanto Co. |
| Madurit | Melamine resins and compounds | Cassella Farbwerke Mainkur, A.G. |
| Maraglas | Epoxy-casting resin | The Marblette Corporation, Div. of Allied Products |
| Marlex | Polyethylenes, polypropylenes, copolymers | Phillips Petroleum Co. |
| Marvinol | Vinyl chloride resins and compounds | Uniroyal Chemical, Div. of Uniroyal Inc. |
| Merlon | Polycarbonate resins | Mobay Chemical Co. |
| Micarta | Melamines, phenolics, polyesters | Westinghouse Electric Co., Industrial Micarta Div. |
| Microthene | Polyethylenes, polyolefins | U.S. Industrial Chemicals Co. |
| Multrathane | Urethane elastomers | Mobay Chemical Company |
| Nopcofoam | Polyurethane plastics | Nopco Chemical Co., Plastics Div. |
| Novodur | Polyacrylonitrile-butadiene-styrene | Farbenfabriken Bayer, A. G. |
| Opalon | Vinyl chloride resins and compounds | Monsanto Co. |
| Paraplex | Polyester resins, acrylic-modified polyester resins | Rohm & Haas Company |

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**TABLE C.9 (continued) Trade Names, Composition, and Manufacturers of Various Plastics**

| *Trade name* | *Composition* | *Manufacturer* |
|---|---|---|
| Permelite | Melamines | Melamine Plastics, Inc., Div. of Fiberlite Corp. |
| Petrothene | Polyethylene resins, polypropylene resins | U.S. Industrial Chemicals Co. |
| Piccoflex | Styrene-copolymer resins | Pennsylvania Industrial Chemical Corp. |
| Piccolastic | Styrene-polymer resins | Pennsylvania Industrial Chemical Corp. |
| Plaskon | Nylons, melamines, phenolics, polyesters | Allied Chemical Corp. |
| Pleogen | Alkyds, polyesters, copolymers | Mol-Rez Div., American Petrochemical Corp. |
| Plexiglas | Acrylics | Rohm & Haas Company |
| Pliovic | Polyvinyl chlorides | The Goodyear Tire & Rubber Co., Chemical Div. |
| Plyophen | Phenolic resins | Reichhold Chemicals, Inc. |
| Poly-Eth | Polyethylene resins | Gulf Oil Corp., U.S. Div. of Gulf Oil Corp. |
| Polylite | Polyester resins | Reichhold Chemicals, Inc. |
| Polypenco | Acrylics, chlorinated polyethers, fluoro-carbons, nylons, polycarbonates | Polymer Corp. |
| Resimene | Urea and melamine resins | Monsanto Co. |
| Resinox | Phenolic resins and compounds | Monsanto Co. |
| Rhonite | Urea resins | Rohm & Haas Company |
| Roylar | Polyurethanes | Uniroyal Chemical, Div. of Uniroyal Inc. |
| Ryertex | Laminated phenolics and rigid polyvinyl chloride extrusions | Joseph T. Ryerson & Son, Inc., Industrial Plastics and Bearings Sales Div. |
| Super Dylan | Polyethylene | Sinclair-Koppers Co. |
| Supreme | Polyethylenes | Johns-Manville Company |
| Sylplast | Urea-formaldehyde compounds | FMC Corp., Organic Chemicals Div. |
| Teflon | Fluorocarbon resins | E. I. du Pont de Nemours & Co., Inc. |
| Tenite | Cellulose acetate, cellulose-acetate-polyethylene, poly-propylenes, urethane elastomers, copolymers | Eastman Chemical Products, Inc., Sub. Eastman Kodak Co. |
| Tetran | Fluorocarbons | Pennsalt Chemicals Corp. |
| Texin | Urethane elastomers | Mobay Chemical Company |
| Thioment | Polyisoprenes | Atlas Minerals & Chemicals Div., The Electric Storage Battery Co. |
| Ultrapas | Melamine resins | Dynamit Nobel, A. G. |
| Ultrathene | Ethylene-vinyl acetates | U.S. Industrial Chemicals Co. |
| Ultron | Polyvinyl chlorides | Monsanto Co. |
| Vibrathane | Urethane elastomers | Uniroyal Chemical, Div. of Uniroyal Inc. |
| Vibrin | Polyester resins | Uniroyal Chemical, Div. of Uniroyal Inc. |
| Vitel | Polyesters | The Goodyear Tire & Rubber Co., Chemical Div. |
| Viton | Synthetic rubbers | E. I. du Pont de Nemours & Co., Inc. |
| Vitroplast | Polyester cements | Atlas Minerals & Chemicals Div., The Electric Storage Battery Co. |
| Vyron | Polyvinyl chlorides | Industrial Vinyls, Inc. |

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## TABLE C.10 Properties of Commercial Nylon Resins*

| *Property* | *Type 6/6* | *Type 6* | *Type 6/10* | *Type 11* | *Glass-reinforced Type 6/6, 40%* | *$MoS_2$-filled, 2½%* | *Direct polymerized, castable* |
|---|---|---|---|---|---|---|---|
| **Mechanical** | | | | | | | |
| Tensile strength, psi | 11,800 | 11,800 | 8209 | 8500 | 30,000 | 10,000 to 14,000 | 11,000 to 14,000 |
| Elongation, % | 60 | 200 | 240 | 120 | 1.9 | 5 to 150 | 10 to 50 |
| Tensile yield stress, psi | 11,800 | 11,800 | 8500 | | 30,000 | | |
| Flexural modulus, psi | 410,000 | 395,000 | 280,000 | 151,000 | 1,800,000 | 450,000 | |
| Tensile modulus, psi | 420,000 | 380,000 | 280,000 | 178,000 | | 450,000 to 600,000 | 350,000 to 450,000 |
| Hardness, Rockwell | 118R | 119R | 111R | 55A | 75E–80E | 110R–125R | 112R–120R |
| Impact strength, tensile, ft-lb/sq in. | 76 | | 160 | | | 50–180 | 80–100 |
| Impact strength, Izod, ft-lb/in. of notch | 0.9 | 1.0 | 1.2 | 3.3 | 3.7** | 0.6 | 0.9 |
| Deformation under load, 2000 psi, 122°F, % | 1.4 | 1.8 | 4.2 | 2.02† | 0.4§ | 0.5 to 2.5 | 0.5 to 1 |
| **Thermal** | | | | | | | |
| Heat-deflection temp, °F | | | | | | | |
| At 66 psi | 360 | 365 | 300 | 154 | 509 | 400 to 490 | 400 to 425 |
| At 264 psi | 150 | 152 | 135 | 118 | 502 | 200 to 470 | 300 to 425 |
| Coefficient of thermal expansion, per °F | $4.5 \times 10^{-5}$ | $4.6 \times 10^{-5}$ | $5 \times 10^{-5}$ | $10 \times 10^{-5}$ | $0.9 \times 10^{-5}$ | $3.5 \times 10^{-5}$ | $5.0 \times 10^{-5}$ |
| Coefficient of thermal conductivity, Btu in./hr ft² °F | 1.7 | 1.7 | 1.5 | | | | |
| Specific heat | 0.3–0.5 | 0.4 | 0.3–0.5 | 0.58 | | | |
| Brittleness temp, °F | −112 | | −166 | | | | |
| **Electrical** | | | | | | | |
| Dielectric strength, short time, v/mil | 385 | 420 | 470 | 425 | 480 | 300 to 400 | 500 to 600‡ |
| Dielectric constant | | | | | | | |
| At 60 hz | 4.0 | 3.8 | 3.9 | | 4.45 | | 3.7 |
| At $10^3$ hz | 3.9 | 3.7 | 3.6 | 3.3 | 4.40 | | 3.7 |
| At $10^6$ hz | 3.6 | 3.4 | 3.5 | | 4.10 | | 3.7 |
| Power factor | | | | | | | |
| At 60 hz | 0.014 | 0.010 | 0.04 | 0.03 | 0.009 | | 0.02 |
| At $10^3$ hz | 0.02 | 0.016 | 0.04 | 0.03 | 0.011 | | 0.02 |
| At $10^6$ hz | 0.04 | 0.020 | 0.03 | 0.02 | 0.018 | | 0.02 |
| Volume resistivity, ohm-cm | $10^{14}$ to $10^{15}$ | $3 \times 10^{15}$ | $10^{14}$ to $10^{15}$ | $2 \times 10^{13}$ | $2.6 \times 10^{15}$ | $2.5 \times 10^{13}$ | |
| **General** | | | | | | | |
| Water absorption, 24 hr, % | 1.5 | 1.6 | 0.4 | 0.4 | 0.6 | 0.5 to 1.4 | 0.9 |
| Specific gravity | 1.13 to 1.15 | 1.13 | 1.07 to 1.09 | 1.04 | 1.52 | 1.14 to 1.18 | 1.15 to 1.17 |
| Melting point, °F | 482 to 500 | 420 to 435 | 405 to 430 | 367 | 480 to 490 | 496 ± 9 | 430 ± 10 |
| Flammability | self ext | self ext | self ext | self ext | self ext | self ext | self ext |
| **Chemical resistance to** | | | | | | | |
| Strong acids | Poor | Poor | Poor | Poor | Poor | Poor | Poor |
| Strong bases | Good | Good | Good | Fair | Good | Good | Good |
| Hydrocarbons | Excellent | Excellent | Excellent | Good | Excellent | Excellent | Excellent |
| Chlorinated hydrocarbons | Good | Good | Good | Fair | Good | Good | Good |
| Aromatic alcohols | Good | Good | Good | Good | Good | Good | Good |
| Aliphatic alcohols | Good | Good | Good | Fair | Good | Good | Good |

*Notes:*

Most nylon resins listed in this table are used for injection molding, and test values are determined from standard injection-molded specimens. In these cases a single typical value is listed. Exceptions are $MoS_2$-filled nylon and direct-polymerized (castable) nylon, which are sold principally in semifinished stock shapes. Ranges of values listed are based on tests on various forms and sizes produced under varying processing conditions.

Because single values apply only to standard molded specimens, and properties vary in finished parts of different sizes and forms produced by various processes, these values should be used for comparison and preliminary design considerations only. For final design purposes the manufacturer should be consulted for test experience with the form being considered. Listed values should not be used for specification purposes.

†2000 psi, 73°F.

‡0.040-in. thick.

**$\frac{1}{2} \times \frac{1}{2}$-in. bar.

§4000 psi, 122°F.

*From: "Nylons", D.D. Carswell, *Machine Design*, 40(29):62, Dec. 12, 1968.

For Conversion factors see Table C.10.

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**TABLE C.11 Properties of Silicate Glasses***

Most of the commercially produced glass is for windows, bottles, and inexpensive containers; it is a soda-lime-silica glass of fairly uniform composition, similar to glass No. 0080 in the table below and in Table 1-93. The following tables on glasses (Tables 1-92 through 1-103) deal largely with that one-tenth of the glass output for which special properties are required. All data are subject to normal manufacturing variations.

Silica glass is inherently high in viscosity and melting point. These are reduced by fluxes such as $Na_2O$, $K_2O$, and $B_2O_3$. Soda and potash glasses have a high expansion coefficient (column 7), while that of fused silica is very low. Because the borosilicate glasses are intermediate, and their thermal shock resistance is high (e.g., Corning Code 7740 glass), they are widely used for laboratory and kitchen glassware. Aluminosilicate glasses are hard, heat-resisting, and of high chemical durability. Glass hardness (indentation) correlates closely with the elastic modulus (column 14). Lead oxide is also used as flux, with a result of reduced softening point and high refractive index: hence its uses for optical glass and art glass.

Sealing of glass with metal calls for close control of the coefficient of expansion (column 7 and Figure 1-99).

*EXPLANATION OF COLUMNS*:

**Column 5:**

| | | |
|---|---|---|
| B—blown ware | P—pressed ware | S—plate glass |
| M—multiform | R—rolled sheet | T—tubing and rod |
| U—panels | LC—large castings | |

**Column 6:**

[2]Since weathering is determined primarily by clouding, which changes transmission, a rating for the opal glasses is omitted.

[3]These borosilicate glasses may rate differently if subjected to excessive heat treatment.

**Column 8:**

Normal service: No breakage from excessive thermal shock is assumed.

Extreme limits: Glass will be very vulnerable to thermal shock. Recommendations in this range are based on mechanical stability considerations only. Tests should be made before adopting final designs. These data are approximate only.

**Column 9:**

Based on plunging sample into cold water after oven heating. Resistance of 100°C means no breakage if heated to 110°C and plunged into water at 10°C. Tempered samples have over twice the resistance of annealed glass. These data are approximate only.

**Column 10:**

[4]These data are estimated.

Resistance in °C is the temperature differential between the two surfaces of a tube or a constrained plate that will cause a tensile stress of 1000 psi on the cooler surface.

**Column 11:**

Viscosity is given in poises. At the strain point the stresses are significantly reduced in a matter of hours, while at the annealing point there is adequate stress reduction in minutes.

**Column 12:**

Data show relative resistance to sandblasting.

**Column 15:**

Data at 25°C are extrapolated from high temperature readings and are approximate only.

*From: "Properties of Selected Commercial Glasses", Publication B-83, Corning Glass Works.

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**TABLE C.11 (continued) Properties of Silicate Glasses***

| 1 | 2 | 3 | 4 | 5 | 6 | | | 7 | | 8 | | | | 9 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Corrosion Resistance | | | Thermal Expansion, $10^{-7}$ in./in./°C. | | Upper Working Temperatures (Mechanical Considerations Only) | | | | Thermal Shock Res. Plates 6" × 6" | | |
| | | | | | | | | | | Annealed | | Tempered | | Annealed | | |
| Glass Code† | Type | Color | Principal Use | Forms Usually Available | Weathering | Water | Acid | 0–300°C 32–572°F | Room Temp.-Setting Point | Normal Service °C. | Extreme Limit °C. | Normal Service °C. | Extreme Limit °C. | ⅛" Thk. °C. | ¼" Thk. °C. | ½" Thk. °C. |
| 0010 | Potash Soda Lead | Clear | Lamp Tubing | T | 2 | 2 | 2 | 93 | 100 | 110 | 380 | | | 65 | 50 | 35 |
| 0080 | Soda Lime | Clear | Lamp Bulbs | B M T | 3 | 2 | 2 | 92 | 103 | 110 | 460 | 220 | 250 | 65 | 50 | 35 |
| 0120 | Potash Soda Lead | Clear | Lamp Tubing | T M | 2 | 2 | 2 | 89 | 98 | 110 | 380 | — | | 65 | 50 | 35 |
| 1720 | Aluminosilicate | Clear | Ignition Tube | B T | 1 | 1 | 3 | 42 | 52 | 200 | 650 | 400 | 450 | 135 | 115 | 75 |
| 1723 | Aluminosilicate | Clear | Electron Tube | B T | 1 | 1 | 3 | 46 | 54 | 200 | 650 | 400 | 450 | 125 | 100 | 70 |
| 1990 | Potash Soda Lead | Clear | Iron Sealing | — | 3 | 3 | 4 | 124 | 136 | 100 | 310 | — | — | 45 | 35 | 25 |
| 2405 | Borosilicate | Red | General | B P U | | | — | 43 | 51 | 200 | 480 | — | — | 135 | 115 | 75 |
| 2475 | Soda Zinc | Red | Neon Signs | T | 3 | 2 | 2 | 93 | — | 110 | 440 | — | — | 65 | 50 | 35 |
| 3320 | Borosilicate | Canary | Tungsten Sealing | | [3]1 | [3]1 | [3]2 | 40 | 43 | 200 | 480 | — | — | 145 | 110 | 80 |
| 6720 | Soda Zinc | Opal | General | P | [2]— | 1 | 2 | 80 | 92 | 110 | 480 | 220 | 275 | 70 | 60 | 40 |
| 6750 | Soda Barium | Opal | Lighting Ware | B P R | [2] | 2 | 2 | 88 | — | 110 | 420 | 220 | 220 | 65 | 50 | 35 |
| 6810 | Soda Zinc | Opal | Lighting Ware | B P R | [2]— | 1 | 2 | 69 | — | 120 | 470 | 240 | 270 | 85 | 70 | 45 |
| 7040 | Borosilicate | Clear | Kovar Sealing | B T | [3]3 | [3]3 | [3]4 | 48 | 54 | 200 | 430 | — | — | — | — | — |
| 7050 | Borosilicate | Clear | Series Sealing | T | [3]3 | [3]3 | [3]4 | 46 | 51 | 200 | 440 | 235 | 235 | 125 | 100 | 70 |
| 7052 | Borosilicate | Clear | Kovar Sealing | B M P T | [3]2 | [3]2 | [3]4 | 46 | 53 | 200 | 420 | 210 | 210 | 125 | 100 | 70 |
| 7056 | Borosilicate | Clear | Kovar Sealing | B T P | 2 | 2 | 4 | 51 | 57 | 200 | 460 | — | — | — | — | — |
| 7070 | Borosilicate | Clear | Low Loss Electrical | B M P T | [3]2 | [3]2 | [3]2 | 32 | 39 | 230 | 430 | 230 | 230 | 180 | 150 | 100 |
| 7250 | Borosilicate | Clear | Seal Beam Lamps | P | [3]1 | [3]2 | [3]2 | 36 | 38 | 230 | 460 | 260 | 260 | 160 | 130 | 90 |
| 7570 | High Lead | Clear | Solder Sealing | — | 1 | 1 | 4 | 84 | 92 | 100 | 300 | — | — | — | — | — |
| 7720 | Borosilicate | Clear | Tungsten Sealing | B P T | [3]2 | [3]2 | [3]2 | 36 | 43 | 230 | 460 | 260 | 260 | 160 | 130 | 90 |
| 7740 | Borosilicate | Clear | General | B P S T U | [3]1 | [3]1 | [3]1 | 33 | 35 | 230 | 490 | 260 | 290 | 180 | 150 | 100 |
| 7760 | Borosilicate | Clear | General | B P | 2 | 2 | 2 | 34 | 37 | 230 | 450 | 250 | 250 | 160 | 130 | 90 |
| 7900[1] | 96% Silica | Clear | High Temp. | B P T U M | 1 | 1 | 1 | 8 | 7 | 800 | 1100 | — | — | 1250 | 1000 | 750 |
| 7913 | 96% Silica | Clear | High Temp. | B P R S T | 1 | 1 | 1 | 8 | 7 | 900 | 1200 | — | — | — | — | — |
| 7940 | Fused Silica | Clear | Ultrasonic | U | 1 | 1 | 1 | 5.5 | 7 | 900 | 1100 | — | — | 1250 | 1000 | 750 |
| 8160 | Potash Soda Lead | Clear | Electron Tubes | P T | 2 | 2 | 3 | 91 | 100 | 110 | 380 | | — | 65 | 50 | 35 |
| 8161 | Potash Lead | Clear | Electron Tubes | P T | 2 | 1 | 4 | 90 | 97 | 110 | 390 | — | — | — | — | — |
| 8363 | High Lead | Clear | Radiation Shielding | L C | 3 | 1 | 4 | 104 | 112 | 100 | 200 | — | — | — | — | — |
| 8871 | Potash Lead | Clear | Capacitors | | 2 | 1 | 4 | 102 | 113 | 125 | 300 | — | — | 55 | 45 | 35 |
| 9010 | Potash Soda Barium | Grey | TV Bulbs | P | 2 | 2 | 2 | 89 | 102 | 110 | 380 | | — | | | |
| 9700 | Borosilicate | Clear | u v Transmission | T U | [3]1 | [3]1 | [3]2 | 39 | 39 | 220 | 500 | — | — | 150 | 120 | 80 |
| 9741 | Borosilicate | Clear | u v Transmission | B U T | [3]3 | [3]3 | [3]4 | 39 | 49 | 200 | 390 | — | | 150 | 120 | 80 |

† Corning Glass Works code numbers are used in this table.

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**TABLE C.11 (continued) Properties of Silicate Glasses***

| 10 | 11 | | | | 12 | 13 | 14 | | | 15 | | | 16 | | | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal Stress Resistance °C. | Viscosity Data† | | | | Impact Abrasion Resistance | Density grams per C.C. | Young's Modulus | | Poisson's Ratio | $Log_{10}$ of Volume Resistivity | | | Dielectric Properties at 1 Mc and 20°C | | | Refractive Index Sod. D Line (.5893 Microns) | Glass Code |
| | Strain Point °C. | Annealing Point °C. | Softening Point °C. | Working Point °C. | | | ($10^6$lb./sq. in) | ($10^6$kg/cm²) | | 25°C. 77°F | 250°C. 482°F | 350°C. 662°F | Power Factor | Dielectric Const. | Loss Factor | | |
| 19 | 395 | 435 | 625 | 985 | 0.8 | 2.86 | 8.9 | 0.63 | .21 | 17.+ | 8.9 | 7.0 | .16% | 6.7 | 1.% | 1.539 | 0010 |
| 17 | 470 | 510 | 695 | 1005 | 1.2 | 2.47 | 10.0 | 0.70 | .24 | 12.4 | 6.4 | 5.1 | .9 | 7.2 | 6.5 | 1.512 | 0080 |
| 20 | 395 | 435 | 630 | 980 | 0.8 | 3.05 | 8.6 | 0.60 | .22 | 17.+ | 10.1 | 8.0 | .12 | 6.7 | .8 | 1.560 | 0120 |
| 28 | 670 | 715 | 915 | 1190 | 2.0 | 2.52 | 12.7 | 0.89 | 0.25 | — | 11.4 | 9.5 | .38 | 7.2 | 2.7 | 1.530 | 1720 |
| 25 | 670 | 710 | 910 | 1175 | 2.0 | 2.64 | 12.5 | 0.88 | 0.25 | — | 13.5 | 11.3 | .16% | 6.3 | 1.0% | 1.547 | 1723 |
| 14 | 330 | 360 | 500 | 755 | — | 3.47 | 8.4 | 0.59 | .25 | — | 10.1 | 7.7 | .04 | 8.3 | .33 | — | 1990 |
| [37] | 500 | 530 | 770 | 1085 | — | 2.50 | 9.9 | 0.70 | 0.21 | — | — | — | — | — | — | 1.507 | 2405 |
| [17] | 440 | 480 | 690 | 1040 | — | 2.59 | 10.0 | 0.70 | — | — | 7.8 | 6.2 | — | — | — | 1.511 | 2475 |
| [40] | 500 | 540 | 780 | 1155 | — | 2.27 | 9.4 | 0.66 | 0.19 | — | 8.6 | 7.1 | .30 | 4.9 | 1.5 | 1.481 | 3320 |
| 19 | 510 | 550 | 775 | 1010 | — | 2.58 | 10.2 | 0.72 | .21 | — | — | — | — | — | — | 1.507 | 6720 |
| [18] | 445 | 485 | 670 | 1040 | — | 2.59 | — | — | — | — | — | — | — | — | — | 1.513 | 6750 |
| [23] | 490 | 530 | 770 | 1010 | — | 2.65 | — | — | — | — | — | — | — | — | — | 1.508 | 6810 |
| 37 | 450 | 490 | 700 | 1080 | — | 2.24 | 8.6 | 0.60 | .23 | — | 9.6 | 7.8 | .20 | 4.8 | 1.0 | 1.480 | 7040 |
| 39 | 460 | 500 | 705 | 1025 | — | 2.24 | 8.7 | 0.61 | .22 | 16. | 8.8 | 7.2 | .33 | 4.9 | 1.6 | 1.479 | 7050 |
| 41 | 435 | 480 | 710 | 1115 | — | 2.28 | 8.2 | 0.58 | .22 | 17. | 9.2 | 7.4 | .26 | 4.9 | 1.3 | 1.484 | 7052 |
| 34 | 470 | 510 | 720 | 1045 | — | 2.29 | 9.2 | 0.65 | .21 | — | 10.2 | 8.3 | .27 | 5.7 | 1.5 | 1.487 | 7056 |
| 66 | 455 | 495 | — | 1070 | 4.1 | 2.13 | 7.4 | 0.52 | .22 | 17.+ | 11.2 | 9.1 | .06 | 4.1 | .25 | 1.469 | 7070 |
| 48 | 490 | 540 | 780 | 1190 | 3.2 | 2.24 | 9.2 | 0.65 | .20 | 15. | 8.2 | 6.7 | .27 | 4.7 | 1.3 | 1.475 | 7250 |
| 21 | 340 | 365 | 440 | 560 | — | 5.42 | 8.0 | 0.56 | .28 | — | 10.6 | 8.7 | .22 | 15. | 3.3 | — | 7570 |
| 49 | 485 | 525 | 755 | 1140 | 3.2 | 2.35 | 9.1 | 0.64 | .20 | 16. | 8.8 | 7.2 | .27 | 4.7 | 1.3 | 1.487 | 7720 |
| 53 | 515 | 565 | 820 | 1245 | 3.1 | 2.23 | 9.1 | 0.64 | .20 | 15. | 8.1 | 6.6 | .50 | 4.6 | 2.6 | 1.474 | 7740 |
| 52 | 480 | 525 | 780 | 1210 | — | 2.23 | 9.1 | 0.64 | — | 17. | 9.4 | 7.7 | .18 | 4.5 | .79 | 1.473 | 7760 |
| 202 | 820 | 910 | 1500 | — | 3.5 | 2.18 | 10.0 | 0.70 | .19 | 17. | 9.7 | 8.1 | .05 | 3.8 | .19 | 1.458 | 7900[1] |
| 211 | 820 | 910 | 1500 | — | 3.5 | 2.18 | 9.6 | 0.67 | .19 | — | 9.7 | 8.1 | .04 | 3.8 | 0.15 | 1.458 | 7913 |
| 290 | 990 | 1050 | 1580 | — | 3.6 | 2.20 | 10.5 | 0.74 | .16 | — | 11.8 | 10.2 | .001 | 3.8 | .0038 | 1.459 | 7940 |
| [18] | 395 | 435 | 630 | 975 | — | 2.98 | — | — | — | — | 10.6 | 8.4 | .09 | 7.0 | .63 | 1.553 | 8160 |
| 22 | 400 | 435 | 600 | 860 | — | 4.00 | 7.8 | 0.55 | .24 | — | 12.0 | 9.9 | .06 | 8.3 | 0.50 | 1.659 | 8161 |
| 19 | 300 | 315 | 380 | 460 | — | 6.22 | 7.4 | 0.52 | .27 | — | 9.2 | 7.5 | .19 | 17.0 | 3.2 | 1.97 | 8363 |
| 17 | 350 | 385 | 525 | 785 | — | 3.84 | 8.4 | 0.59 | .26 | — | 11.1 | 8.8 | .05 | 8.4 | .42 | — | 8871 |
| 18 | 405 | 445 | 650 | 1010 | — | 2.64 | 9.8 | 0.69 | .21 | — | 8.9 | 7.0 | .17 | 6.3 | 1.1 | 1.507 | 9010 |
| 45 | 520 | 565 | 805 | 1200 | — | 2.26 | 9.6 | 0.67 | .20 | 15. | 8.0 | 6.5 | — | — | — | 1.478 | 9700 |
| 55 | 410 | 450 | 705 | — | — | 2.16 | 7.2 | 0.51 | .23 | 17.+ | 9.4 | 7.6 | — | — | — | 1.468 | 9741 |

†Viscosities at these four temperatures are approximately as follows: $10^{14.5}$ poises at the strain point, $10^{13}$ poises at the annealing point, $10^{7.8}$ poises at the softening point, at $10^4$ poises at the working point.

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**TABLE C.12 Properties of Window Glass*: Transmittance of Sheet and Plate Glass**

| *Type or tint* | *Nominal thickness, in.* | *Weight, lb/ft²* | *Transmittance* | |
|---|---|---|---|---|
| | | | *Total visible daylight, %* | *Direct 90° solar energy, %* |
| Sheet | $\frac{1}{16}$ | 0.81 | 91 | 89 |
| Sheet | $\frac{5}{64}$ | 1.00 | 91 | 88 |
| Sheet | $\frac{3}{32}$ | 1.22 | 90 | 87 |
| Sheet | $\frac{1}{8}$ | 1.64 | 90 | 86 |
| Sheet | $\frac{3}{16}$ | 2.47 | 89 | 84 |
| Sheet | $\frac{7}{32}$ | 2.85 | 89 | 82 |
| Plate or float | $\frac{1}{8}$ | 1.64 | 90 | 86 |
| Plate or float | $\frac{1}{4}$ | 3.28 | 88 | 79 |
| Plate or float | $\frac{5}{16}$ | 4.09 | 88 | 77 |
| Plate or float | $\frac{3}{8}$ | 4.91 | 87 | 74 |
| Plate or float | $\frac{1}{2}$ | 6.55 | 86 | 70 |
| Plate or float | $\frac{5}{8}$ | 8.18 | 85 | 65 |
| Plate or float | $\frac{3}{4}$ | 9.83 | 83 | 60 |
| Plate or float | $\frac{7}{8}$ | 11.45 | 81 | 55 |
| Plate or float | 1 | 13.13 | 79 | 49 |
| Gray[a] | $\frac{1}{4}$ | 3.28 | 43 | 46 |
| Bronze[a] | $\frac{1}{4}$ | 3.28 | 49 | 45 |
| Green[a] | $\frac{1}{4}$ | 3.28 | 75 | 46 |
| Double[b] | $\frac{1}{4}$ each | 6.56 | 78 | — |

*Note:* Many types of glass are available, including tempered heat-strengthened glass, laminated shatterproof glass, conductive-coated glass, reflective-coated glass. Several double-pane combinations are offered.

Direct 90° transmittance of solar ultraviolet radiation through non-tinted window glass is about 85 percent as high as the values for total solar energy transmittance. Ultraviolet transmittance of gray or bronze glass is lower.

Infrared transmittance is considerably lower than visual transmittance. This is significant in view of the large percentage of infrared radiation from most sources.

Visible reflectance of untinted glass is about 8 percent.

Approximate shading coefficients, ASHRAE, $\frac{1}{4}$-in. glass only: clear, 0.93; gray, 0.67; bronze, 0.65; green, 0.67.

Overall heat transfer coefficient of window area (air to air) is usually assumed to be 1.0 Btu/ft² hr, but it is lower if there is no wind.

For other data on shading coefficients, spectral transmittance, coated glass, special glasses, etc., see Tables 1-91, 2-19, and 7-19.

[a]Transmittance of tinted glass depends on depth of tint.
[b]Two $\frac{1}{4}$-in. panes with $\frac{1}{2}$-in. air space, sealed.

*Tables compiled from several sources.

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**TABLE C.13 Properties and Uses of American Woods***

| *Species* | *Specific gravity* | | *Characteristics* | *Uses* | *Weight* | | |
|---|---|---|---|---|---|---|---|
| | *Green* | *Dry* | | | *lb/cu ft, green* | *lb/cu ft, air-dry 12%* | *lb/1000 board ft, air-dry 12%* |
| Alder, red | 0.37 | 0.41 | Low shrinkage; moderate in strength, shock resistance, hardness, and weight† | Furniture; sash; doors; millwork | 46 | 28 | 2330 |
| Ash, black | 0.45 | 0.49 | Light in weight† | Cabinets; veneer; cooperage, containers | 52 | 34 | 2830 |
| Ash, Oregon | 0.50 | 0.55 | Similar to but lighter than white ash† | Similar to white ash | 46 | 38 | 3160 |
| Ash, white | 0.54 | 0.58 | Heavy; hard; stiff; strong; high shock resistance† | Handles; ladder rungs; baseball bats; farm implements; car parts | 48 | 41 | 3420 |
| Bald cypress (Southern cypress) | | | Moderate in strength, weight, hardness, and shrinkage** | Building construction; beams; posts; ties; tanks; ships; paneling | 51 | 32 | 2670 |
| Beech, American | 0.56 | 0.64 | Heavy; high strength, shock resistance, and shrinkage; uniform texture† | Flooring; furniture; handles; kitchenwear; ties (treated) | 54 | 45 | 3750 |
| Birch | 0.57 | 0.63 | Heavy; high strength, shock resistance, and shrinkage; uniform texture† | Interior finish; dowels; ties (treated); veneer; musical instruments | 57 | 44 | 3670 |
| Cottonwood | 0.37 | 0.40 | Uniform texture; does not split readily; moderate in weight, strength, hardness, and shrinkage | Crates; trunks; car parts; farm implements | 49 | 28 | 2330 |
| Douglas fir | 0.41 | 0.44 | Moderate in strength, weight, shock resistance, and shrinkage‡ | Building and construction; poles; veneer; plywood; ships; furniture; boxes | 38 | 34 | 2830 |
| Elm | 0.57 | 0.63 | Moderate in strength, weight, and hardness; high in shock resistance and shrinkage; good in bending† | Cooperage; baskets; crates; veneer; vehicle parts | 54 | 34 | 2920 |
| Hemlock, Eastern | 0.38 | 0.40 | Moderate in weight, strength, and hardness† | Building and construction; boxes | 50 | 28 | 2330 |
| Hemlock, Western | 0.38 | 0.42 | Moderate in weight, strength, and hardness† | Sash; doors; posts; piles; building and construction | 41 | 29 | 2420 |
| Hickory, true | 0.65 | 0.73 | High toughness, hardness, shock resistance, strength, and shrinkage† | Dowels; spokes; poles; shafts; gymnasium equipment | 63 | 51 | 4250 |
| Incense cedar | 0.35 | | Uniform texture; easy to season; low shrinkage; shock resistance, weight, and stiffness** | Lumber; fence posts; ties; poles; shingles | 45 | | |
| Larch, Western | 0.48 | 0.52 | Moderate in strength, weight, shock resistance, hardness, and shrinkage‡ | Doors; sash; posts; pilings; building and construction | 48 | 36 | 3000 |

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**TABLE C.13 (continued) Properties and Uses of American Woods***

| Species | Specific gravity | | Characteristics | Uses | Weight | | |
|---|---|---|---|---|---|---|---|
| | Green | Dry | | | lb/cu ft, green | lb/cu ft, air-dry 12% | lb/1000 board ft, air-dry 12% |
| Locust, black | 0.66 | 0.69 | High in shock resistance, weight, and hardness; very high strength; moderate shrinkage** | Mine timbers; posts; poles; ties | 58 | 48 | 4000 |
| Maple | 0.44 | 0.48 | High in hardness, weight, strength, shock resistance, and shrinkage; uniform texture† | Flooring; furniture; trim; spools; farm implements | 54 | 40 | 3330 |
| Oak, red and white | 0.57 | 0.63 | High in hardness, weight, strength, shock resistance, and shrinkage; red†, white‡ | Trim; ships; flooring; ties; furniture; cooperage; piles | 64 | 44 | 3670 |
| Pine, jack | | | Coarse texture; low strength, stiffness, shock resistance, and shrinkage | Box lumber; fuel; mine timber; ties; poles; posts | | | |
| Pine, lodgepole | 0.38 | 0.41 | Moderate in weight, hardness, strength, shock resistance, and shrinkage; easy to work‡ | Poles; mine timber; ties; construction | 39 | 29 | 2420 |
| Pine | | | High shrinkage; moderate strength, stiffness, hardness, and shock resistance | General construction; ties; poles; posts | | | |
| Pine, Ponderosa | 0.38 | 0.40 | Moderate in weight, shock resistance, shrinkage, and hardness; easy to work† | Building; paneling; sash; frames | 45 | 28 | 2330 |
| Pine, S. yellow | 0.47 | 0.51 | Moderate in shock resistance, shrinkage, and hardness; high in strength‡ | Building and construction; poles; pilings; boxes | 55 | 41 | 3420 |
| Pine, sugar | 0.35 | 0.36 | Low shock resistance; easy to work; moderate strength† | Sash; counters; blinds; patterns | 52 | 25 | 2080 |
| Pine, Western white | 0.36 | 0.38 | Moderate in strength, shock resistance, shrinkage, and hardness; easy to work† | Building and construction; patterns; boxes | 35 | 27 | 2250 |
| Red cedar, Eastern and Western | 0.44 | 0.47 | High shock resistance; low stiffness and shrinkage; moderate in strength and hardness** | Fence posts; closet liners; chests; flooring | 37 | 37 | 2750 |
| Redwood | 0.38 | 0.40 | Low shrinkage; medium in weight, strength, hardness, and shock resistance** | Posts; doors; interiors; cooling towers | 50 | 28 | 2330 |
| Spruce, Eastern | 0.38 | 0.40 | Moderate in hardness, shock resistance, weight, shrinkage, and strength† | Building; millwork; boxes; ladders | 34 | 28 | 2330 |

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**TABLE C.13 (continued) Properties and Uses of American Woods***

| *Species* | *Specific gravity* | | *Characteristics* | *Uses* | *Weight* | | |
|---|---|---|---|---|---|---|---|
| | *Green* | *Dry* | | | *lb/cu ft, green* | *lb/cu ft, air-dry 12%* | *lb/1000 board ft, air-dry 12%* |
| Spruce, Engelmann | 0.31 | 0.33 | Generally straight grained; light in weight; low strength as a beam or post; low shock resistance; moderate shrinkage | Mine timber; ties; poles; flooring; studding; paper | 39 | 23 | 1920 |
| Spruce, Sitka | 0.37 | 0.40 | Moderate in weight, hardness, strength, shock resistance, and shrinkage† | Important in boat and plane construction; sash; doors; boxes; siding | 33 | 28 | 2330 |
| Sycamore | 0.46 | 0.49 | High shrinkage; moderate in weight, strength, hardness, and shock resistance† | Boxes; ties; posts; veneer; flooring; butcher blocks | 52 | 34 | 2830 |
| Tamarack | 0.49 | 0.53 | Coarse texture; moderate in strength, hardness, shrinkage, and shock resistance | Ties; mine timber; posts; poles; tanks; scaffolding | 47 | 37 | 3080 |
| Tupelo | | | Uniform texture; moderate in strength, hardness, shock resistance; high shrinkage; interlocked grain makes splitting difficult† | Flooring; planking; crates; furniture | | | |
| Walnut, black | 0.51 | 0.55 | Moderate shrinkage; high weight, strength, hardness, and shock resistance; easily worked and glued** | Gun stocks; cabinets; plywood; furniture; veneer | 58 | 38 | 3170 |
| White cedar | 0.31 | 0.32 | Low shrinkage, weight, shock resistance, and strength; soft; easily worked** | Poles; posts; ties; tanks; ships | 24 | 23 | 1920 |
| Willow, black | | | High strength and shock resistance; low beam strength and weight; interlocked grain | Lumber; veneer; charcoal; furniture; sub-flooring; studding | | | |

†Decay resistance low.
‡Decay resistance medium.
**Decay resistance high.
*From: "Materials Data Book", E.R. Parker, McGraw-Hill Book Company, 1967, pp. 252–255.

*Note:* For weight-density in kg/m$^3$, multiply value in lb/ft$^3$ by 16.02.

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**TABLE C.14 Properties of Natural Fibers***

Because there are great variations within a given fiber class, average properties may be misleading. The following typical values are only a rough comparative guide.

| *Name* | *Specific gravity* | *Tenacity, g/denier* | *Tensile strength, $10^3$ psi* | *Elongation at break (dry), %* | *Standard regain, % of dry*[b] | *Fiber diameter, microns* | *Fiber length, in.* | *Fiber shape and kind* | *Resistant to* |
|---|---|---|---|---|---|---|---|---|---|
| ANIMAL ORIGIN | | | | | | | | | |
| Wool | 1.32 | 1.0–1.7 | 17–29 | 23–35 | 15–18 | 17–40 | 1.5–5 | Oval, crimped, scales | Age, weak acids, solvents |
| Silk | 1.25 | 3.5–5 | 90 | 20–25 | 10 | 10–13 | | Flexible, soft, smooth | Heat, solvents, weak acids, wear |
| Cashmere | | | | | | 15–16 | 1–4 | Round, scales, soft | |
| Mohair | 1.32 | 1.2–1.5 | | 30 | 13 | 24–50 | 6–12 | Round, silky | Wear, age, solvents, weak acids |
| Camel hair | 1.32 | 1.8 | | 40 | 13 | 10–40 | 1–6 | Oval, striated | Age, solvents |
| VEGETABLE ORIGIN | | | | | | | | | |
| Cotton | 1.54 | 2–5 | 30–120 | 5–11 | 7.5–8.5 | 10–20 | 0.5–2 | Flat, convoluted, ribbon | Age, heat, washing, wear, solvents, alkalies, insects |
| Jute (bast) | 1.5 | | 50 | 1–1.5 | 14 | 15–20 | | Woody, rough, polygon | |
| Sisal (leaf) | 1.49 | 2.2 | 75 | 2–2.5 | 13 | 10–30 | Strand 30–40 | Stiff, straight | |
| Flax (bast) | 1.52 | 4–7 | | 2–3 | 12 | 15–18 | Strand 40–50 | Soft, fine | Age, solvents, washing, insects, weak acids, and alkalies |
| Kenaf (bast) | | | 45 | | | 15–30 | | Polygon or oval | |
| Hemp (bast) | 1.48 | | | 2 | | 18–25 | Strand 30–70 | Polygon or oval, irregular | |
| Henequen (leaf) | | | 60 | | | | Strand 30–60 | Finer than sisal | |
| Abaca (leaf) (Manila) | 1.48 | 2.3–2.9 | 100 | 2–3 | 13 | | Strand 30–120 | | |
| MINERAL ORIGIN | | | | | | | | | |
| Asbestos | 2.5 | | 40–200 | | | Various | 0.5–10 | Smooth, straight | Heat to 400 deg C, acids, chemicals, organisms |
| Glass[a] | 2.5 | 7–12 | 200–500 | 3–4.5 | 0 | Various | | Circular, smooth | Chemicals, insects |
| Silicate[a] (Ca, Al, Mg) | 2.85 | | | | 0 | | | | Heat to 900 deg C, most chemicals, insects, rot |

*Note:* Wide variations may be expected, especially for different grades of cotton. Wet strength is lower (for rayon, very much lower), but it depends on the duration of soaking. The strength of yarn is only a fraction of the cumulative strength of all individual fibers.

Most fibers exhibit relaxation of stress at constant strain and also increase in elongation at constant load (creep). The stress-strain curve is greatly affected by the rate of extension. When the stress is removed, there is a quick elastic recovery, a delayed recovery, and a permanent set. Hence the elastic behavior of any fiber depends on its stress-strain history. The elastic recoveries of nylon and wool are high; those of cotton, flax, and rayon are much lower.

The heat capacity (specific heat) of most fibers is about one-third that of water.

*Other fibers:* Fur hair is slightly coarser than silk fibers. Camel and llama hairs are almost as coarse as wool but only about one-third the size of human hair. Horse hair is over 100 microns; hog bristles, over 200 microns. Jute, sisal, and hemp are intermediate between cotton and wool. These are rough average sizes, and many natural fibers range 50% above or below such averages.

[a]Here classified as natural fibers for convenience, although they are man-made by processing.
[b]Expected equilibrium moisture regain of dry fiber, in percent of dry weight, when exposed in air at 70 deg F, 65% relative humidity.

*Compiled from several sources.

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**TABLE C.15 Properties of Manufactured Fibers***

| *Chemical class; common name (sources)* | *Specific gravity* | *Tenacity, g/denier* | *Tensile strength, $10^3$ psi* | *Elongation at break, %* | *Regain (standard)* | *Softening point, deg C* | *Melting point, deg C* | *Flammability* | *Brittleness temp, deg C* |
|---|---|---|---|---|---|---|---|---|---|
| CELLULOSE FIBERS (NATURAL) | | | | | | | | | |
| Acetate | 1.30 | 1.–1.3 | 18–25 | 20–30 | 6.5 | 140 | 230 | Melts and burns | |
| Triacetate | 1.32 | 1.2–1.4 | 20–28 | 25–30 | 3–4.5 | 225 | 300 | Melts and burns | |
| Viscose rayon | 1.51 | 2–2.6 | 30–46 | 17–25 | 13. | | 200[a] | Burns readily | |
| High-tenacity viscose | 1.53 | 3–5 | 60–80 | 10–12 | 10 | | 200[a] | Burns readily | < −114 |
| Polynosic viscose | 1.53 | 3–5 | 60–80 | 8–20 | 7 | | 200[a] | Burns readily | |
| Cuprammonium rayon (cupro) | 11.52 | 1.7–2.3 | 30–45 | 10–17 | 12.5 | | 250[a] | Burns readily | |
| PROTEIN FIBERS (NATURAL) | | | | | | | | | |
| Animal: casein (milk) | 1.3 | 1.0 | 15 | 60–70 | 14 | 100 | 150 | Slow | |
| Vegetable—seed: soybeans, peanuts, corn | 1.3 | 0.7–0.9 | 11–14 | 40–60 | 11–15 | 150 | 250 | Slow | |
| Vegetable—latex: rubber (vulcanized) | 1.0 | 0.4–0.6 | 4–7 | 700–900 | 0 | 300 | | Burns | −60 |
| SYNTHETIC FIBERS | | | | | | | | | |
| Polyacrylonitrile (acrylic) | 1.17 | 2–5 | 50–75 | 25–40 | 2 | 190 | 260 | Burns | |
| Polyamide (nylon) | 1.14 | 4–9 | 70–120 | 20–40 | 4 | 200 | 215–250 | Slow | < −100 |
| Polyester (PET dacron) | 1.38 | 4–8 | 70–120 | 10–50 | 0.4 | 225 | 250–290 | Low | |
| Polyethylene (olefin, low density) | 0.92 | 3–6 | 40–70 | 25–40 | 0.15 | 90–120 | 120 | Slow | −114 |
| Polyethylene (olefin, high density) | 0.95 | 5–7 | 60–80 | 10–20 | 0.01 | 120–130 | 140 | Slow | −114 |
| Polypropylene (olefin) | 0.91 | 4.5–8 | 45–80 | 15–30 | 0–0.5 | 145 | 160–170 | Self-ext. low | −70 |
| Polyurethane (spandex) | 1.1 | 0.5–1.0 | 7–16 | 500–700 | 1.0 | 190 | 250 | Burns | |
| Polyvinyl chloride (PVC) | 1.38 | 0.7–2 | 12–17 | 100–125 | 0.1 | 70 | 140[a] | No; chars | < −100 |
| Polyvinyl alcohol (PVA) | 1.3 | 3–7 | 60–90 | 15–28 | 5 | 230 | 240 | Slow | |
| Polyvinylidene chloride (saran) | 1.7 | 2 | 40 | 20–30 | 0.1 | 115–135 | 170 | No | |
| Polytetrafluoroethylene (PTFE) | 2.1 | 1.2–1.4 | 33 | 15–30 | 0 | 225 | 300[a] | No | |

*Note:* Mechanical properties are for room temperature and humidity and based on unstressed cross section.

[a]Decomposition; does not melt.

*Compiled from several sources.

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## TABLE C.16 Properties of Rubbers and Elastomers*

Elastomers cannot be classified in any brief and simple manner, nor are they well characterized by the usual mechanical tests. The terms *rubber* and *synthetic rubber* are loosely applied to a great variety of elastic materials, from pure gum natural rubber and pure synthetics to cured, compounded, filled, and even reinforced products.

ASTM designations (D1418) by chemical polymer description are used in the following table; yet within each class the properties can vary widely, depending on the exact composition, heat treatment service temperature, and application. Typical uses, such as rubber springs and cushioning, permit an almost unlimited number of combinations of design variables.

Mechanically, rubbers may be expected to lose strength rapidly with increase in temperature, to show a large hysteresis in stress-strain behavior, to exhibit marked creep and set, and to be greatly affected by rates of load application or frequency of repeated stress. "Heat build-up", i.e., increase in temperature in service, as well as deterioration from environment (sunlight, oils, ozone, etc.) will reduce the valuable properties of many rubbers, both natural and synthetic.

The following data apply to typical samples of commercial elastomers for common uses.

*KEY:*

A—Acetone
B—Benzene
C—Carbon tetrachloride
D—Carbon disulfide
E—Phenol
F—Sulfur compounds
G—Glycerol or glycol
H—Hexane
I—Acids
J—Alkalies
K—Ketones
L—Alcohols
M—Ammonia
N—Turpentine
O—Coal derivatives; bitumens
P—Petroleum products
R—Aromatics
S—Salts
T—Heat or high temperature
U—Ultraviolet
V—Vegetable oils
W—Weathering
X—Oxidation
Y—Aging
Z—Ozone

| *Chemical name* | *Polyisoprene* | *Butadiene* | *Styrene-butadiene* | *Acrylonitrile butadiene* |
|---|---|---|---|---|
| *Other names* | *Natural (or synthetic) rubber NR (IR)* | *BR Cis 4* | *Buna S Styrene SBR, GR-S* | *Nitrile, Buna N Hycar NBR, GR-A* |
| CHEMICAL AND PHYSICAL | | | | |
| Specific gravity | 0.93 | 1.0 | 1.0 | 1.0 |
| Specific heat | 0.40 | 0.45 | 0.40 | 0.47 |
| Thermal conductivity | | | | |
| W/cm·K | 0.001 7 | 0.002 5 | 0.002 6 | 0.002 5 |
| Btu/hr·ft·deg F | 0.10 | 0.14 | 0.15 | 0.14 |
| Service temperature, deg C | | | | |
| min | −25 | −40 | −20 | −20 |
| max | 90 | 90 | 75 | 110 |
| Solvents, softeners | D,K,P,V | D,H,N,P | K,P,R,V | C,K,O,R |
| Resistant to | A,I,J,L | G,I,J,W,Y | G,I,L,S,X | G,I,K,L,P,S, T,V,W |
| Swelled by | D,P,V | A,P,V | P,V | A,E,N |
| MECHANICAL AND ELECTRICAL | | | | |
| Tensile strength | | | | |
| $kg/cm^2$ (max) | 300. | 210. | 210. | 295. |
| kpsi (max) | 4.3 | 3.0 | 3.0 | 4.2 |
| Elongation at break, % | 600. | 700. | 600. | 600. |
| Vol. resistivity, ohm-cm | $10^{15}$ | $10^{15}$ | $10^{14}$ | $10^{10}$ |
| Dielectric strength | | | | |
| kV/cm | 235 | | 235 | 185 |
| V/mil | 600. | | 600. | 475. |
| Dielectric constant | 3.0 | 2.3 | 2.8 | 3.0 |
| Power factor (50–100 Hz) | 0.003 | 0.005 | 0.005 | 0.007 |
| Rebound | Good | Good | Fair | Good |
| COMPARATIVE RATINGS—RESISTANCE TO | | | | |
| Abrasion | Good | Excellent | Good | Excellent |
| Cold flow (set) | Excellent | | Good | Good |
| Tearing | Good | | Poor | Fair |
| Air permeability | Fair | Good | Fair | Excellent |
| Oxidation | Fair | Fair | Fair | Fair |
| Flame | Poor | | Poor | Poor |

*Compiled from several sources.

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**TABLE C.16 (continued) Properties of Rubbers and Elastomers***

| *Chemical name* | *Polychloro-prene* | *Isobutylene-isoprene* | *Polysulfide* | *Polymethane* |
|---|---|---|---|---|
| *Other names* | *Neoprene[a] CR, GR-M* | *Butyl IIR, GR-I* | *Thiokol[a] PS, GR-P* | *Adiprene[a] PU* |
| CHEMICAL AND PHYSICAL | | | | |
| Specific gravity | 1.25 | 0.95 | 1.4 | 1.2 |
| Specific heat | 0.5 | 0.45 | 0.31 | 0.45 |
| Thermal conductivity | | | | |
| W/cm·K | 0.002 1 | 0.001 3 | 0.003 | 0.001 3 |
| Btu/hr·ft·deg F | 0.12 | 0.075 | 0.17 | 0.075 |
| Service temperature, deg C | | | | |
| min | −20 | −40 | −15 | −35 |
| max | 100 | 120 | 90 | 120 |
| Solvents, softeners | A,B,C,D,I,N,R | D,P | C | |
| Resistant to | G,L,P,S,T,U,V, W,Y,Z | E,G,J,S,U,V, W,X,Y,Z | L,P,U,Z | P,V,X,Z |
| Swelled by | C,D,N,R | D,H,P | C,R | B,C,K,R |
| MECHANICAL AND ELECTRICAL | | | | |
| Tensile strength | | | | |
| $kg/cm^2$ (max) | 240. | 175. | 90. | 350. |
| kpsi (max) | 3.5 | 2.5 | 1.3 | 5.0 |
| Elongation at break, % | 800. | 700. | 500. | 550. |
| Vol. resistivity, ohm-cm | $10^{11}$ | $10^{17}$ | $10^{8}$ | $10^{11}$ |
| Dielectric strength | | | | |
| kV/cm | 195 | 295 | 125 | 195 |
| V/mil | 500 | 750 | 325 | 500 |
| Dielectric constant | 7. | 2.4 | 8. | 7. |
| Power factor (50–100 Hz) | .04 | 0.004 | 0.02 | 0.04 |
| Rebound | Good | Poor | Poor | |
| COMPARATIVE RATINGS—RESISTANCE TO | | | | |
| Abrasion | Excellent | Fair | Poor | Excellent |
| Cold flow (set) | Excellent | Fair | Poor | Poor |
| Tearing | Good | Good | Poor | Excellent |
| Air permeability | Good | Excellent | Good | Excellent |
| Oxidation | Good | Good | Good | Good |
| Flame | Excellent | Poor | Poor | Poor |

[a]Proprietary.

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# Appendix D. Gases and Vapors

## TABLE D.1 SI Units — Definitions, Abbreviations and Prefixes

**BASIC UNITS—MKS**

| | | | | | |
|---|---|---|---|---|---|
| Length | meter | m | Electric current | ampere | A |
| Mass | kilogram | kg | Thermodynamic temperature | kelvin | K |
| Time | second | s | Luminous intensity | candela | cd |

**DERIVED UNITS**

| *Property* | *Units*† | *Abbreviations and dimensions* | |
|---|---|---|---|
| Acceleration | meter per second squared | $m/s^2$ | |
| Activity (of radioactive source) | 1 per second | $s^{-1}$ | |
| Angular acceleration | radian per second squared | $rad/s^{-1}$ | |
| Angular velocity | radian per second | rad/s | |
| Area | square meter | $m^2$ | |
| Density | kilogram per cubic meter | $kg/m^3$ | |
| Dynamic viscosity | newton-second per sq meter | $N{\cdot}s/m^2$ | |
| Electric capacitance | farad | F | $(A{\cdot}s/V)$ |
| Electric charge | coulomb | C | $(A{\cdot}s)$ |
| Electric field strength | volt per meter | V/m | |
| Electric resistance | ohm | | (V/A) |
| Entropy | joule per kelvin | J/K | |
| Force | newton | N | $(kg{\cdot}m/s^2)$ |
| Frequency | hertz | hz | $(s^{-1})$ |
| Illumination | lux | lx | $(lm/m^2)$ |
| Inductance | henry | H | $(V{\cdot}s/A)$ |
| Kinematic viscosity | sq meter per second | $m^2/s$ | |
| Luminance | candela per sq meter | $cd/m^2$ | |
| Luminous flux | lumen | lm | $(cd{\cdot}sr)$ |
| Magnetomotive force | ampere | A | |
| Magnetic field strength | ampere per meter | A/m | |
| Magnetic flux | weber | Wb | $(V{\cdot}s)$ |
| Magnetic flux density | tesla | T | $(Wb/m^2)$ |
| Power | watt | W | (J/s) |
| Pressure | newton per square meter | $N/m^2$ | |
| Radiant intensity | watt per steradian | W/sr | |
| Specific heat | joule per kilogram kelvin | J/kg K | |
| Thermal conductivity | watt per meter kelvin | W/m K | |
| Velocity | meter per second | m/s | |
| Volume | cubic meter | $m^3$ | |
| Voltage, potential difference, electromotive force | volt | V | (W/A) |
| Wave number | 1 per meter | $m^{-1}$ | |
| Work, energy, quantity of heat | joule | J | $(N{\cdot}m)$ |

**PREFIX NAMES OF MULTIPLES AND SUBMULTIPLES OF UNITS**

| *Decimal equivalent* | *Prefix* | *Pronunciation* | *Symbol* | *Exponential expression* |
|---|---|---|---|---|
| 1,000,000,000,000 | tera | tĕr′ȧ | T | $10^{+12}$ |
| 1,000,000,000 | giga | jĭ′gȧ | G | $10^{+9}$ |
| 1,000,000 | mega | mĕg′ȧ | M | $10^{+6}$ |
| 1,000 | kilo | kĭl′ō | k | $10^{+3}$ |
| 100 | hecto | hĕk′tō | h | $10^{+2}$ |
| 10 | deka | dĕk′ȧ | da | 10 |
| 0.1 | deci | dĕs′ĭ | d | $10^{-1}$ |
| 0.01 | centi | sĕn′tĭ | c | $10^{-2}$ |
| 0.001 | milli | mĭl′ĭ | m | $10^{-3}$ |
| 0.000 001 | micro | mī′krō | $\mu$ | $10^{-6}$ |
| 0.000 000 001 | nano | năn′ō | n | $10^{-9}$ |
| 0.000 000 000 001 | pico | pē′kō | p | $10^{-12}$ |
| 0.000 000 000 000 001 | femto | fĕm′tō | f | $10^{-15}$ |
| 0.000 000 000 000 000 001 | atto | ăt′tō | a | $10^{-18}$ |

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# Appendix E. Miscellaneous

**TABLE E.1 Sizes and Allowable Unit Stresses for Softwood Lumber**

**American Softwood Lumber Standard.** A voluntary standard for softwood lumber has been developing since 1922. Five editions of Simplified Practice Recommendation R16 were issued from 1924–53 by the Department of Commerce; the present NBS voluntary Product Standard PS 20-70, "American Softwood Lumber Standard", was issued in 1970. It was supported by the American Lumber Standards Committee, which functions through a widely representative National Grading Rule Committee.

## Part a. Nominal and Minimum-Dressed Sizes of Lumber*

| *Item* | *Thicknesses* | | | *Face widths* | | |
|---|---|---|---|---|---|---|
| | *Nominal* | *Minimum-dressed* | | *Nominal* | *Minimum-dressed* | |
| | | *Dry,[a] inches* | *Green, inches* | | *Dry,[a] inches* | *Green, inches* |
| Boards[b] | | | | 2 | $1\frac{1}{2}$ | $1\frac{9}{16}$ |
| | | | | 3 | $2\frac{1}{2}$ | $2\frac{9}{16}$ |
| | | | | 4 | $3\frac{1}{2}$ | $3\frac{9}{16}$ |
| | | | | 5 | $4\frac{1}{2}$ | $4\frac{5}{8}$ |
| | 1 | $\frac{3}{4}$ | $\frac{25}{32}$ | 6 | $5\frac{1}{2}$ | $5\frac{5}{8}$ |
| | | | | 7 | $6\frac{1}{2}$ | $6\frac{5}{8}$ |
| | $1\frac{1}{4}$ | 1 | $1\frac{1}{32}$ | 8 | $7\frac{1}{4}$ | $7\frac{1}{2}$ |
| | | | | 9 | $8\frac{1}{4}$ | $8\frac{1}{2}$ |
| | $1\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{9}{32}$ | 10 | $9\frac{1}{4}$ | $9\frac{1}{2}$ |
| | | | | 11 | $10\frac{1}{4}$ | $10\frac{1}{2}$ |
| | | | | 12 | $11\frac{1}{4}$ | $11\frac{1}{2}$ |
| | | | | 14 | $13\frac{1}{4}$ | $13\frac{1}{2}$ |
| | | | | 16 | $15\frac{1}{4}$ | $15\frac{1}{2}$ |
| Dimension | | | | 2 | $1\frac{1}{2}$ | $1\frac{9}{16}$ |
| | | | | 3 | $2\frac{1}{2}$ | $2\frac{9}{16}$ |
| | | | | 4 | $3\frac{1}{2}$ | $3\frac{9}{16}$ |
| | 2 | $1\frac{1}{2}$ | $1\frac{9}{16}$ | 5 | $4\frac{1}{2}$ | $4\frac{5}{8}$ |
| | $2\frac{1}{2}$ | 2 | $2\frac{1}{16}$ | 6 | $5\frac{1}{2}$ | $5\frac{5}{8}$ |
| | 3 | $2\frac{1}{2}$ | $2\frac{9}{16}$ | 8 | $7\frac{1}{4}$ | $7\frac{1}{2}$ |
| | $3\frac{1}{2}$ | 3 | $3\frac{1}{16}$ | 10 | $9\frac{1}{4}$ | $9\frac{1}{2}$ |
| | | | | 12 | $11\frac{1}{4}$ | $11\frac{1}{2}$ |
| | | | | 14 | $13\frac{1}{4}$ | $13\frac{1}{2}$ |
| | | | | 16 | $15\frac{1}{4}$ | $15\frac{1}{2}$ |
| Dimension | | | | 2 | $1\frac{1}{2}$ | $1\frac{9}{16}$ |
| | | | | 3 | $2\frac{1}{2}$ | $2\frac{9}{16}$ |
| | | | | 4 | $3\frac{1}{2}$ | $3\frac{9}{16}$ |
| | | | | 5 | $4\frac{1}{2}$ | $4\frac{5}{8}$ |
| | 4 | $3\frac{1}{2}$ | $3\frac{9}{16}$ | 6 | $5\frac{1}{2}$ | $5\frac{5}{8}$ |
| | $4\frac{1}{2}$ | 4 | $4\frac{1}{16}$ | 8 | $7\frac{1}{4}$ | $7\frac{1}{2}$ |
| | | | | 10 | $9\frac{1}{4}$ | $9\frac{1}{2}$ |
| | | | | 12 | $11\frac{1}{4}$ | $11\frac{1}{2}$ |
| | | | | 14 | | $13\frac{1}{2}$ |
| | | | | 16 | | $15\frac{1}{2}$ |
| Timbers | 5 and thicker | | $\frac{1}{2}$ off | 5 and wider | | $\frac{1}{2}$ off |

[a] Maximum moisture content of 19% or less.

[b] Boards less than the minimum thickness for 1 in. nominal but $\frac{5}{8}$ in. or greater thickness dry ($\frac{11}{16}$ in. green) may be regarded as American Standard Lumber, but such boards shall be marked to show the size and condition of seasoning at the time of dressing. They shall also be distinguished from 1-in. boards on invoices and certificates.

*Reprinted from: "American Softwood Lumber Standard", NBS PS 20-70, National Bureau of Standards, 1970; available from Superintendent of Documents.

*Note:* This table applies to boards, dimensional lumber, and timbers. The thicknesses apply to all widths and all widths to all thicknesses.

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**TABLE E.1 (continued) Sizes and Allowable Unit Stresses for Softwood Lumber**

The "American Softwood Lumber Standard", PS 20-70, gives the size and grade provisions for American Standard lumber and describes the organization and procedures for compliance enforcement and review. It lists commercial name classifications and complete definitions of terms and abbreviations.

Eleven softwood species are listed in PS 20-70, viz., cedar, cypress, fir, hemlock, juniper, larch, pine, redwood, spruce, tamarack, and yew. Five dimensional tables show the standard dressed (surface planed) sizes for almost all types of lumber, including matched tongue-and-grooved and shiplapped flooring, decking, siding, etc. Dry or seasoned lumber must have 19% or less moisture content, with an allowance for shrinkage of 0.7–1.0% for each four points of moisture content below the maximum. Green lumber has more than 19% moisture. Table A illustrates the relation between nominal size and dressed or green sizes.

**National Design Specification.** Part b is condensed from the 1971 edition of "National Design Specification for Stress-Grade Lumber and Its Fastenings," as recommended and published by the National Forest Products Association, Washington, D.C. This specification was first issued by the National Lumber Manufacturers Association in 1944; subsequent editions have been issued as recommended by the Technical Advisory Committee. The 1971 edition is a 65-page bulletin with a 20-page supplement giving "Allowable Unit Stresses, Structural Lumber," from which Part b has been condensed. The data on working stresses in this Supplement have been determined in accordance with the corresponding ASTM Standards, D245-70 and D2555-70.

## Part b. Species, Sizes, Allowable Stresses, and Modulus of Elasticity of Lumber

Normal loading conditions: Moisture content not over 19%, No. 1 grade, visual grading. To convert psi to N/m$^2$, multiply by 6 895.

| *Species*[a] | *Sizes, nominal* | *Typical grading agency, 1971*[b] | *Allowable unit stresses, psi*[d] | | | | *Modulus of elasticity, psi* |
|---|---|---|---|---|---|---|---|
| | | | *Extreme fiber in bending*[c] | *Tension parallel to grain* | *Compression perpendicular* | *Compression parallel* | |
| CEDAR | | | | | | | |
| Northern white | 2 × 4 | NL, NH | 1 100 | 600 | 205 | 675 | 800 000 |
| | 2 or 4 × 6+ | NL, NH | 1 000 | 575 | 205 | 675 | 800 000 |
| Western | 2 × 4 | NC | 1 450 | 725 | 285 | 975 | 1 100 000 |
| | 2 or 4 × 6+ | NC, WW | 1 250 | 725 | 285 | 975 | 1 100 000 |
| FIR | | | | | | | |
| Balsam | 2 × 4 | NL, NH | 1 300 | 675 | 170 | 825 | 1 200 000 |
| | 2 or 4 × 6+ | NL, NH | 1 150 | 650 | 170 | 825 | 1 200 000 |
| Douglas (larch) | 2 × 4 | WC, NC | 2 400 | 1 200 | 385 | 1 250 | 1 800 000 |
| | 2 or 4 × 6+ | WC, NC | 1 750 | 1 000 | 385 | 1 250 | 1 800 000 |
| HEMLOCK | | | | | | | |
| Eastern (tamarack) | 2 × 4 | NL, NH | 1 750 | 900 | 365 | 1 050 | 1 300 000 |
| | 2 or 4 × 6+ | NL, NH | 1 500 | 875 | 365 | 1 050 | 1 300 000 |
| Hem-fir | 2 × 4 | WC, NC | 1 600 | 825 | 245 | 1 000 | 1 500 000 |
| | 2 or 4 × 6+ | WC, NC | 1 400 | 800 | 245 | 1 000 | 1 500 000 |
| Mountain | 2 × 4 | WC, WW | 1 700 | 850 | 370 | 1 000 | 1 300 000 |
| | 2 or 4 × 6+ | WC, WW | 1 450 | 850 | 370 | 1 000 | 1 300 000 |
| PINE | | | | | | | |
| Idaho white | 2 × 4 | WW | 1 400 | 725 | 240 | 925 | 1 400 000 |
| | 2 or 4 × 6+ | WW | 1 200 | 700 | 240 | 925 | 1 400 000 |
| Lodgepole | 2 × 4 | WW | 1 500 | 750 | 250 | 900 | 1 300 000 |
| | 2 or 4 × 6+ | WW | 1 300 | 750 | 250 | 900 | 1 300 000 |

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**TABLE E.1 (continued) Sizes and Allowable Unit Stresses for Softwood Lumber**

| *Species*[a] | *Sizes, nominal* | *Typical grading agency, 1971*[b] | *Allowable unit stresses, psi*[d] | | | | *Modulus of elasticity, psi* |
|---|---|---|---|---|---|---|---|
| | | | *Extreme fiber in bending*[c] | *Tension parallel to grain* | *Compression perpendicular* | *Compression parallel* | |
| PINE *(continued)* | | | | | | | |
| Northern | 2×4 | NL, NH | 1 600 | 825 | 280 | 975 | 1 400 000 |
| | 2 or 4×6+ | NL, NH | 1 400 | 800 | 280 | 975 | 1 400 000 |
| Ponderosa (sugar) | 2×4 | WW, NC | 1 400 | 700 | 250 | 850 | 1 200 000 |
| | 2 or 4×6+ | WW, NC | 1 200 | 700 | 250 | 850 | 1 200 000 |
| Red | 2×4 | NC | 1 350 | 700 | 280 | 825 | 1 300 000 |
| | 2 or 4×6+ | NC | 1 150 | 675 | 280 | 825 | 1 300 000 |
| Southern | 2×4 | SP | 2 000 | 1 000 | 405 | 1 250 | 1 800 000 |
| | 2 or 4×6+ | SP | 1 750 | 1 000 | 405 | 1 250 | 1 800 000 |
| REDWOOD | | | | | | | |
| California | 2 or 4×2 or 4 | RI | 1 950 | 1 000 | 425 | 1 250 | 1 400 000 |
| | 2 or 4×6 to 12 | RI | 1 700 | 1 000 | 425 | 1 250 | 1 400 000 |
| SPRUCE | | | | | | | |
| Eastern | 2×4 | NL, NH | 1 500 | 750 | 255 | 900 | 1 400 000 |
| | 2 or 4×6+ | NL, NH | 1 250 | 750 | 255 | 900 | 1 400 000 |
| Engelmann | 2×4 | WW | 1 300 | 675 | 195 | 725 | 1 200 000 |
| | 2 or 4×6+ | WW | 1 150 | 650 | 195 | 725 | 1 200 000 |
| Sitka | 2×4 | WC | 1 550 | 775 | 280 | 925 | 1 500 000 |
| | 2 or 4×6+ | WC | 1 300 | 775 | 280 | 925 | 1 500 000 |

*Note:* Allowable unit stresses in horizontal shear are in the range of 60–100 psi for No. 1 grade.

[a]Grade designations are not entirely uniform. Values in the table apply approximately to "No. 1." There is seldom more than one better grade than No. 1, and this may be designated as select, select structural, dense, or heavy. In addition to lower grades 2 and 3, there may be other lower grades, designated as construction, standard, stud, and utility. In bending and tension the allowable unit stresses in the lowest recognized grade (utility) are of the order of $\frac{1}{8}$ to $\frac{1}{6}$ of the allowable stresses for grade No. 1. The tabular values for allowable bending stress are for the extreme fiber in "repetitive member uses," and edgewise use. The original tables give correction factors, which are less than unity for moist locations and for short-time loading; they are greater than unity if the moisture content of the wood in service is 15% or less. In general, all data apply to uses within covered structures. From the extensive tables, only the No. 1 grade in nominal 2 × 4 size and 2-in. or 4-in. planks, 6 in., and wider have been selected for illustration.

In a few cases the allowable stresses specified for the Canadian products will vary slightly from those given here for the same species by the U.S. agencies.

[b]Grading agencies represented by letters in this column are as follows:

NC = National Lumber Grades Authority (a Canadian agency)
NH = Northern Hardwood and Pine Manufacturers Association
NL = Northern Lumber Manufacturers Association
RI = Redwood Inspection Service
SP = Southern Pine Inspection Bureau
WC = West Coast Lumber Inspection Bureau
WW = Western Wood Products Association

[c]It is assumed that all members are so framed, anchored, tied, and braced that they have the necessary rigidity.

[d]For short term loads, these values may be increased: add 15% for 2-month snow load; add 33% for wind or earthquake; add 100% for impact load.

**REFERENCES**

"Wood Handbook", Handbook No. 72, U.S. Department of Agriculture, 1955.

"Timber Construction Manual", American Institute of Timber Construction, John Wiley & Sons, Inc., 1966.

"National Design Specification for Stress-Grade Lumber and Its Fastenings", National Forest Products Association, Washington D.C., 1971.

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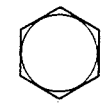
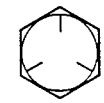
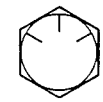
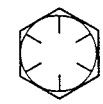
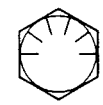
**TABLE E.2 Standard Grades of Bolts**

## Part a: SAE Grades for Steel Bolts

| SAE grade no. | Size range incl. | Proof strength,† kpsi | Tensile strength,† kpsi | Material | Head marking |
|---|---|---|---|---|---|
| 1 | ¼–1½ | | | Low- or medium-carbon steel |  |
| 2 | ¼–¾<br>⅞–1½ | 55<br>33 | 74<br>60 | | |
| 5 | ¼–1 | 85 | 120 | Medium-carbon steel, Q & T |  |
| | 1⅛–1½ | 74 | 105 | | |
| 5.2 | ¼–1 | 85 | 120 | Low-carbon martensite steel, Q & T |  |
| 7 | ¼–1½ | 105 | 133 | Medium-carbon alloy steel, Q & T‡ | |
| 8 | ¼–1½ | 120 | 150 | Medium-carbon alloy steel, Q & T |  |
| 8.2 | ¼–1 | 120 | 150 | Low-carbon martensite steel, Q & T |  |

†Minimum values.
‡Roll threaded after heat treatment.
SOURCES: See "Helpful Hints," by Russell, Burdsall & Ward Corp., Mentor, Ohio 44060; and Chap. 23.

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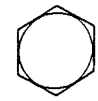
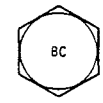
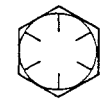
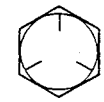
**TABLE E.2 (continued) Standard Grades of Bolts**

## Part b: ASTM Grades for Steel Bolts

| ASTM designation | Size range incl. | Proof strength,† kpsi | Tensile strength,† kpsi | Material | Head marking |
|---|---|---|---|---|---|
| A307 | ¼ to 4 | | | Low-carbon steel |  |
| A325 type 1 | ½ to 1<br>1⅛ to 1½ | 85<br>74 | 120<br>105 | Medium-carbon steel, Q & T | |
| A325 type 2 | ½ to 1<br>1⅛ to 1½ | 85<br>74 | 120<br>105 | Low-carbon martensite steel, Q & T | |
| A325 type 3 | ½ to 1<br>1⅛ to 1½ | 85<br>74 | 120<br>105 | Weathering steel, Q & T | |
| A354 grade BC | | | | Alloy steel, Q & T |  |
| A354 grade BD | ¼ to 4 | 120 | 150 | Alloy steel, Q & T |  |
| A449 | ¼ to 1<br>1⅛ to 1½<br>1¾ to 3 | 85<br>74<br>55 | 120<br>105<br>90 | Medium-carbon steel, Q & T |  |
| A490type | ½ to 1½ | 120 | 150 | Alloy steel, Q & T | |
| A490type 3 | | | | Weathering steel, Q & T | |

† Minimum value.

Sources: See "Helpful Hints," by Russell,Burdsall&Ward Corp.,Mentor,Ohio 44060; and Chapter 23.

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**TABLE E.2 (continued) Standard Grades of Bolts**

## Part c: Metric Mechanical Property Classes for Steel Bolts, Screws, and Studs

| Property class | Size range incl. | Proof strength, MPa | Tensile strength, MPa | Material | Head marking |
|---|---|---|---|---|---|
| 4.6 | M5–M36 | 225 | 400 | Low- or medium-carbon steel | |
| 4.8 | M1.6–M16 | 310 | 420 | Low- or medium-carbon steel | |
| 5.8 | M5–M24 | 380 | 520 | Low- or medium-carbon steel | |
| 8.8 | M16–M36 | 600 | 830 | Medium-carbon steel, Q & T | |
| 9.8 | M1.6–M16 | 650 | 900 | Medium-carbon steel, Q & T | |
| 10.9 | M5–M36 | 830 | 1040 | Low-carbon martensite steel, Q & T | |
| 12.9 | M1.6–M36 | 970 | 1220 | Alloy steel, Q & T | |

**sources: "Helpful Hints," by Russell, Burdsall & Waard Corp,. Mentor, Ohio 44060; see also Chapter 23 and SAEstandard J1199, and ASTM standard F568.**

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**TABLE E.3 Steel Pipe Sizes**

| *Nominal Pipe Size, in.* | *Outside Diameter, in.* | *Schedule Number or Weight* | *Wall Thickness, in.* | *Inside Diameter, in.* | *Surface Area* | | *Areas and Weights Cross-sectional* | | *Weight* |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Outside, ft²/ft* | *Inside, ft²/ft* | *Metal Area, in.²* | *Flow Area, in.²* | *Pipe lb/ft* |
| ⅜ | 1.05 | 40 | 0.113 | 0.824 | 0.275 | 0.216 | 0.333 | 0.533 | 1.131 |
| | | 80 | 0.154 | 0.742 | 0.275 | 0.194 | 0.434 | 0.432 | 1.474 |
| 1 | 1.315 | 40 | 0.133 | 1.049 | 0.344 | 0.275 | 0.494 | 0.864 | 1.679 |
| | | 80 | 0.179 | 0.957 | 0.344 | 0.250 | 0.639 | 0.719 | 2.172 |
| 1¼ | 1.660 | 40 | 0.140 | 1.38 | 0.434 | 0.361 | 0.668 | 1.496 | 2.273 |
| | | 80 | 0.191 | 1.278 | 0.434 | 0.334 | 0.881 | 1.283 | 2.997 |
| 1½ | 1.900 | 40 | 0.145 | 1.61 | 0.497 | 0.421 | 0.799 | 2.036 | 2.718 |
| | | 80 | 0.200 | 1.50 | 0.497 | 0.393 | 1.068 | 1.767 | 3.632 |
| 2 | 2.375 | 40 | 0.154 | 2.067 | 0.622 | 0.541 | 1.074 | 3.356 | 3.653 |
| | | 80 | 0.218 | 1.939 | 0.622 | 0.508 | 1.477 | 2.953 | 5.022 |
| 2½ | 2.875 | 40 | 0.203 | 2.469 | 0.753 | 0.646 | 1.704 | 4.79 | 5.794 |
| | | 80 | 0.276 | 2.323 | 0.753 | 0.608 | 2.254 | 4.24 | 7.662 |
| 3 | 3.5 | 40 | 0.216 | 3.068 | 0.916 | 0.803 | 2.228 | 7.30 | 7.58 |
| | | 80 | 0.300 | 2.900 | 0.916 | 0.759 | 3.016 | 6.60 | 10.25 |
| 3½ | 4.0 | 40 | 0.226 | 3.548 | 1.047 | 0.929 | 2.680 | 9.89 | 9.11 |
| | | 80 | 0.318 | 3.364 | 1.047 | 0.881 | 3.678 | 8.89 | 12.51 |
| 4 | 4.5 | 40 | 0.237 | 4.026 | 1.178 | 1.054 | 3.17 | 12.73 | 10.79 |
| | | 80 | 0.337 | 3.826 | 1.178 | 1.002 | 4.41 | 11.50 | 14.99 |
| 5 | 5.563 | 10 S | 0.134 | 5.295 | 1.456 | 1.386 | 2.29 | 22.02 | 7.77 |
| | | 40 | 0.258 | 5.047 | 1.456 | 1.321 | 4.30 | 20.01 | 14.62 |
| | | 80 | 0.375 | 4.813 | 1.456 | 1.260 | 6.11 | 18.19 | 20.78 |
| 6 | 6.625 | 10 S | 0.134 | 6.357 | 1.734 | 1.664 | 2.73 | 31.7 | 9.29 |
| | | 40 | 0.280 | 6.065 | 1.734 | 1.588 | 5.58 | 28.9 | 18.98 |
| | | 80 | 0.432 | 5.761 | 1.734 | 1.508 | 8.40 | 26.1 | 28.58 |
| 8 | 8.625 | 10 S | 0.148 | 8.329 | 2.258 | 2.180 | 3.94 | 54.5 | 13.40 |
| | | 30 | 0.277 | 8.071 | 2.258 | 2.113 | 7.26 | 51.2 | 24.7 |
| | | 80 | 0.500 | 7.625 | 2.258 | 1.996 | 12.76 | 45.7 | 43.4 |
| 10 | 10.75 | 10 S | 0.165 | 10.420 | 2.81 | 2.73 | 5.49 | 85.3 | 18.7 |
| | | 30 | 0.279 | 10.192 | 2.81 | 2.67 | 9.18 | 81.6 | 31.2 |
| | | Extra heavy | 0.500 | 9.750 | 2.81 | 2.55 | 16.10 | 74.7 | 54.7 |
| 12 | 12.75 | 10 S | 0.180 | 12.390 | 3.34 | 3.24 | 7.11 | 120.6 | 24.2 |
| | | 30 | 0.330 | 12.09 | 3.34 | 3.17 | 12.88 | 114.8 | 43.8 |
| | | Extra heavy | 0.500 | 11.75 | 3.34 | 3.08 | 19.24 | 108.4 | 65.4 |
| 14 | 14.0 | 10 | 0.250 | 13.5 | 3.67 | 3.53 | 10.80 | 143.1 | 36.7 |
| | | Standard | 0.375 | 13.25 | 3.67 | 3.47 | 16.05 | 137.9 | 54.6 |
| | | extra heavy | 0.500 | 13.00 | 3.67 | 3.40 | 21.21 | 132.7 | 72.1 |
| 16 | 16.0 | 10 | 0.250 | 15.50 | 4.19 | 4.06 | 12.37 | 188.7 | 42.1 |
| | | Standard | 0.375 | 15.25 | 4.19 | 3.99 | 18.41 | 182.7 | 62.6 |
| | | extra heavy | 0.500 | 15.00 | 4.19 | 3.93 | 24.35 | 176.7 | 82.8 |
| 18 | 18.0 | 10 S | 0.188 | 17.624 | 4.71 | 4.61 | 10.52 | 243.9 | 35.8 |
| | | Standard | 0.375 | 17.25 | 4.71 | 4.52 | 20.76 | 233.7 | 70.6 |
| | | extra heavy | 0.500 | 17.00 | 4.71 | 4.45 | 27.49 | 227.0 | 93.5 |
| 20 | 20.0 | 10 S | 0.218 | 19.564 | 5.24 | 5.12 | 13.55 | 300.6 | 46.1 |
| | | Standard | 0.375 | 19.25 | 5.24 | 5.04 | 23.12 | 291 | 78.6 |
| | | extra heavy | 0.500 | 19.00 | 5.24 | 4.97 | 30.6 | 283.5 | 104.1 |
| 22 | 22.0 | 10 | 0.250 | 21.50 | 5.76 | 5.63 | 17.1 | 363 | 58.1 |
| | | Standard | 0.375 | 21.25 | 5.76 | 5.56 | 25.5 | 355 | 86.6 |
| | | extra heavy | 0.500 | 21.00 | 5.76 | 5.50 | 33.8 | 346 | 114.8 |
| 24 | 24.0 | 10 | 0.250 | 23.50 | 6.28 | 6.15 | 18.7 | 434 | 63.4 |
| | | Standard | 0.375 | 23.25 | 6.28 | 6.09 | 27.8 | 425 | 94.6 |
| | | extra heavy | 0.500 | 23.00 | 6.28 | 6.02 | 36.9 | 415 | 125.5 |
| 26 | 26.0 | Standard | 0.375 | 25.25 | 6.81 | 6.61 | 30.2 | 501 | 102.6 |
| | | extra heavy | 0.500 | 25.00 | 6.81 | 6.54 | 40.1 | 491 | 136.2 |
| 30 | 30.0 | 10 | 0.312 | 29.376 | 7.85 | 7.69 | 29.1 | 678 | 98.9 |
| | | Standard | 0.375 | 29.250 | 7.85 | 7.66 | 34.9 | 672 | 118.7 |
| | | extra heavy | 0.500 | 29.00 | 7.85 | 7.59 | 46.3 | 661 | 157.6 |
| 34 | 34.0 | Standard | 0.375 | 33.250 | 8.90 | 8.70 | 39.6 | 868 | 134.7 |
| | | extra heavy | 0.500 | 33.00 | 8.90 | 8.64 | 52.6 | 855 | 178.9 |
| 36 | 36.0 | Standard | 0.375 | 35.25 | 9.42 | 9.23 | 42.0 | 976 | 142.7 |
| | | extra heavy | 0.500 | 35.00 | 9.42 | 9.16 | 55.8 | 962 | 189.6 |
| 42 | 42.0 | Standard | 0.375 | 41.25 | 11.0 | 10.8 | 49.0 | 1336 | 166.7 |
| | | extra heavy | 0.500 | 41.00 | 11.0 | 10.73 | 65.2 | 1320 | 221.6 |

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**TABLE E.4 Commercial Copper Tubing***

The following table gives dimensional data and weights of copper tubing used for automotive, plumbing, refrigeration, and heat exchanger services. For additional data see the standards handbooks of the Copper Development Association, Inc., the ASTM standards, and the "SAE Handbook."

Dimensions in this table are actual specified measurements, subject to accepted tolerances. Trade size designations are usually by actual OD, except for water and drainage tube (plumbing), which measures 1/8-in. larger OD. A 1/2-in. plumbing tube, for example, measures 5/8-in. OD, and 2-in. plumbing tube measures 2 1/8-in. OD.

## KEY TO GAGE SIZES

Standard-gage wall thicknesses are listed by numerical designation (14 to 21), BWG or Stubs gage. These gage sizes are standard for tubular heat exchangers. The letter *A* designates SAE tubing sizes for automotive service. Letter designations *K* and *L* are the common sizes for plumbing services, soft or hard temper.

## OTHER MATERIALS

These same dimensional sizes are also common for much of the commercial tubing available in aluminum, mild steel, brass, bronze, and other alloys. Tube weights in this table are based on copper at 0.323 lb/in$^3$. For other materials the weights should be multiplied by the following approximate factors:

| | | | |
|---|---|---|---|
| aluminum | 0.30 | monel | 0.96 |
| mild steel | 0.87 | stainless steel | 0.89 |
| brass | 0.95 | | |

| *Size, OD* | | *Wall Thickness* | | | *Flow Area* | | *Metal* | *Surface Area* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *in.* | *mm* | *in.* | *mm* | *gage* | *in.*$^2$ | *mm*$^2$ | *Area, in.*$^2$ | *Inside, ft*$^2$*/ft* | *Outside, ft*$^2$*/ft* | *Weight, lb/ft* |
| 1/8 | 3.2 | .030 | 0.76 | A | 0.003 | 1.9 | 0.012 | 0.017 | 0.033 | 0.035 |
| 3/16 | 4.76 | .030 | 0.76 | A | 0.013 | 8.4 | 0.017 | 0.034 | 0.049 | 0.058 |
| 1/4 | 6.4 | .030 | 0.76 | A | 0.028 | 18.1 | 0.021 | 0.050 | 0.066 | 0.080 |
| 1/4 | 6.4 | .049 | 1.24 | 18 | 0.018 | 11.6 | 0.031 | 0.038 | 0.066 | 0.120 |
| 5/16 | 7.94 | .032 | 0.81 | 21A | 0.048 | 31.0 | 0.028 | 0.065 | 0.082 | 0.109 |
| 3/8 | 9.53 | .032 | 0.81 | 21A | 0.076 | 49.0 | 0.033 | 0.081 | 0.098 | 0.134 |
| 3/8 | 9.53 | .049 | 1.24 | 18 | 0.060 | 38.7 | 0.050 | 0.072 | 0.098 | 0.195 |
| 1/2 | 12.7 | .032 | 0.81 | 21A | 0.149 | 96.1 | 0.047 | 0.114 | 0.131 | 0.182 |
| 1/2 | 12.7 | .035 | 0.89 | 20L | 0.145 | 93.6 | 0.051 | 0.113 | 0.131 | 0.198 |
| 1/2 | 12.7 | .049 | 1.24 | 18K | 0.127 | 81.9 | 0.069 | 0.105 | 0.131 | 0.269 |
| 1/2 | 12.7 | .065 | 1.65 | 16 | 0.108 | 69.7 | 0.089 | 0.97 | 0.131 | 0.344 |
| 5/8 | 15.9 | .035 | 0.89 | 20A | 0.242 | 156 | 0.065 | 0.145 | 0.164 | 0.251 |
| 5/8 | 15.9 | .040 | 1.02 | L | 0.233 | 150 | 0.074 | 0.143 | 0.164 | 0.285 |
| 5/8 | 15.9 | .049 | 1.24 | 18K | 0.215 | 139 | 0.089 | 0.138 | 0.164 | 0.344 |
| 3/4 | 19.1 | .035 | 0.89 | 20A | 0.363 | 234 | 0.079 | 0.178 | 0.196 | 0.305 |
| 3/4 | 19.1 | .042 | 1.07 | L | 0.348 | 224 | 0.103 | 0.174 | 0.196 | 0.362 |
| 3/4 | 19.1 | .049 | 1.24 | 18K | 0.334 | 215 | 0.108 | 0.171 | 0.196 | 0.418 |
| 3/4 | 19.1 | .065 | 1.65 | 16 | 0.302 | 195 | 0.140 | 0.162 | 0.196 | 0.542 |
| 3/4 | 19.1 | .083 | 2.11 | 14 | 0.268 | 173 | 0.174 | 0.151 | 0.196 | 0.674 |
| 7/8 | 22.2 | .045 | 1.14 | L | 0.484 | 312 | 0.117 | 0.206 | 0.229 | 0.455 |
| 7/8 | 22.2 | .065 | 1.65 | 16K | 0.436 | 281 | 0.165 | 0.195 | 0.229 | 0.641 |
| 7/8 | 22.2 | .083 | 2.11 | 14 | 0.395 | 255 | 0.206 | 0.186 | 0.229 | 0.800 |
| 1 | 25.4 | .065 | 1.65 | 16 | 0.594 | 383 | 0.181 | 0.228 | 0.262 | 0.740 |
| 1 | 25.4 | .083 | 2.11 | 14 | 0.546 | 352 | 0.239 | 0.218 | 0.262 | 0.927 |
| 1 1/8 | 28.6 | .050 | 1.27 | L | 0.825 | 532 | 0.176 | 0.268 | 0.294 | 0.655 |

*Compiled and computed.

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**TABLE E.4 (continued) Commercial Copper Tubing***

| *Size, OD* | | *Wall Thickness* | | | *Flow Area* | | *Metal Area,* | *Surface Area* | | *Weight,* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *Inside,* | *Outside,* | |
| *in.* | *mm* | *in.* | *mm* | *gage* | *in.²* | *mm²* | *in.²* | *ft²/ft* | *ft²/ft* | *lb/ft* |
| 1 1/8 | 28.6 | .065 | 1.65 | 16K | 0.778 | 502 | 0.216 | 0.261 | 0.294 | 0.839 |
| 1 1/4 | 31.8 | .065 | 1.65 | 16 | 0.985 | 636 | 0.242 | 0.293 | 0.327 | 0.938 |
| 1 1/4 | 31.8 | .083 | 2.11 | 14 | 0.923 | 596 | 0.304 | 0.284 | 0.327 | 1.18 |
| 1 3/8 | 34.9 | .055 | 1.40 | L | 1.257 | 811 | 0.228 | 0.331 | 0.360 | 0.884 |
| 1 3/8 | 34.9 | .065 | 1.65 | 16K | 1.217 | 785 | 0.267 | 0.326 | 0.360 | 1.04 |
| 1 1/2 | 38.1 | .065 | 1.65 | 16 | 1.474 | 951 | 0.294 | 0.359 | 0.393 | 1.14 |
| 1 1/2 | 38.1 | .083 | 2.11 | 14 | 1.398 | 902 | 0.370 | 0.349 | 0.393 | 1.43 |
| 1 5/8 | 41.3 | .060 | 1.52 | L | 1.779 | 1148 | 0.295 | 0.394 | 0.425 | 1.14 |
| 1 5/8 | 41.3 | .072 | 1.83 | K | 1.722 | 1111 | 0.351 | 0.388 | 0.425 | 1.36 |
| 2 | 50.8 | .083 | 2.11 | 14 | 2.642 | 1705 | 0.500 | 0.480 | 0.628 | 1.94 |
| 2 | 50.8 | .109 | 2.76 | 12 | 2.494 | 1609 | 0.620 | 0.466 | 0.628 | 2.51 |
| 2 1/8 | 54.0 | .070 | 1.78 | L | 3.095 | 1997 | 0.449 | 0.520 | 0.556 | 1.75 |
| 2 1/8 | 54.0 | .083 | 2.11 | 14K | 3.016 | 1946 | 0.529 | 0.513 | 0.556 | 2.06 |
| 2 5/8 | 66.7 | .080 | 2.03 | L | 4.77 | 3078 | 0.645 | 0.645 | 0.687 | 2.48 |
| 2 5/8 | 66.7 | .095 | 2.41 | 13K | 4.66 | 3007 | 0.760 | 0.637 | 0.687 | 2.93 |
| 3 1/8 | 79.4 | .090 | 2.29 | L | 6.81 | 4394 | 0.950 | 0.771 | 0.818 | 3.33 |
| 3 1/8 | 79.4 | .109 | 2.77 | 12K | 6.64 | 4284 | 1.034 | 0.761 | 0.818 | 4.00 |
| 3 5/8 | 92.1 | .100 | 2.54 | L | 9.21 | 5942 | 1.154 | 0.897 | 0.949 | 4.29 |
| 3 5/8 | 92.1 | .120 | 3.05 | 11K | 9.00 | 5807 | 1.341 | 0.886 | 0.949 | 5.12 |
| 4 1/8 | 104.8 | .110 | 2.79 | L | 11.92 | 7691 | 1.387 | 1.022 | 1.080 | 5.38 |
| 4 1/8 | 104.8 | .134 | 3.40 | 10K | 11.61 | 7491 | 1.682 | 1.009 | 1.080 | 6.51 |

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**TABLE E.5 Standard Gages for Wire, Sheet, and Twist Drills**

| Gage | (1) Mfrs. steel sheet | (2) USS steel sheet (old) | (3) Birmingham or Stub | (4) W & M or Roebling steel wire | (5) AWG or B & S nonferrous wire or sheet | Numbered twist drills | Copper wire (AWG) | | | Sheet steel |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Circular mils | Ohms/1000 ft, 77°F | Lb/1000 ft | Lb/sq ft |
| 0000000 | | 0.500 | | 0.4900 | | | | | | 20.00 |
| 000000 | | 0.469 | | 0.4615 | 0.580 | | | | | 18.75 |
| 00000 | | 0.438 | | 0.4305 | 0.516 | | | | | 17.50 |
| 0000 | | 0.406 | .454 | 0.3938 | 0.460 | | 212,000 | 0.0500 | 641.0 | 16.25 |
| 000 | | 0.375 | .425 | 0.3625 | 0.410 | | 168,000 | 0.0630 | 508.0 | 15 |
| 00 | | 0.344 | .380 | 0.3310 | 0.365 | | 133,000 | 0.0795 | 403.0 | 13.75 |
| 0 | | 0.313 | .340 | 0.3065 | 0.325 | | 106,000 | 0.100 | 319.0 | 12.50 |
| 1 | | 0.281 | .300 | 0.2830 | 0.289 | 0.2280 | 83,700 | 0.126 | 253.0 | 11.25 |
| 2 | | 0.266 | .284 | 0.2625 | 0.258 | 0.2210 | 66,400 | 0.159 | 201.0 | 10.625 |
| 3 | .2391 | 0.250 | .259 | 0.2437 | 0.229 | 0.2130 | 52,600 | 0.201 | 159.0 | 10 |
| 4 | .2242 | 0.234 | .238 | 0.2253 | 0.204 | 0.2090 | 41,700 | 0.253 | 126.0 | 9.375 |
| 5 | .2092 | 0.219 | .220 | 0.2070 | 0.182 | 0.2055 | 33,100 | 0.319 | 100.0 | 8.75 |
| 6 | .1943 | 0.203 | .203 | 0.1920 | 0.162 | 0.2040 | 26,300 | 0.403 | 79.5 | 8.125 |
| 7 | .1793 | 0.188 | .180 | 0.1770 | 0.144 | 0.2010 | 20,800 | 0.508 | 63.0 | 7.5 |
| 8 | .1644 | 0.172 | .165 | 0.1620 | 0.128 | 0.1990 | 16,500 | 0.641 | 50.0 | 6.875 |
| 9 | .1495 | 0.156 | .148 | 0.1483 | 0.114 | 0.1960 | 13,100 | 0.808 | 39.6 | 6.25 |
| 10 | .1345 | 0.141 | .134 | 0.1350 | 0.102 | 0.1935 | 10,400 | 1.02 | 31.4 | 5.625 |
| 11 | .1196 | 0.125 | .120 | 0.1205 | 0.0907 | 0.1910 | 8,230 | 1.28 | 24.9 | 5 |
| 12 | .1046 | 0.109 | .109 | 0.1055 | 0.0808 | 0.1890 | 6,530 | 1.62 | 19.8 | 4.375 |
| 13 | .0897 | 0.0937 | .095 | 0.0915 | 0.0720 | 0.1850 | 5,180 | 2.04 | 15.7 | 3.75 |
| 14 | .0747 | 0.0781 | .083 | 0.0800 | 0.0641 | 0.1820 | 4,110 | 2.58 | 12.4 | 3.125 |
| 15 | .0673 | 0.0703 | .072 | 0.0720 | 0.0571 | 0.1800 | 3,260 | 3.25 | 9.86 | 2.813 |
| 16 | .0598 | 0.0625 | .065 | 0.0625 | 0.0508 | 0.1770 | 2,580 | 4.09 | 7.82 | 2.5 |
| 17 | .0538 | 0.0562 | .058 | 0.0540 | 0.0453 | 0.1730 | 2,050 | 5.16 | 6.20 | 2.25 |
| 18 | .0478 | 0.0500 | .049 | 0.0475 | 0.0403 | 0.1695 | 1,620 | 6.51 | 4.92 | 2 |
| 19 | .0418 | 0.0437 | .042 | 0.0410 | 0.0359 | 0.1660 | 1,290 | 8.21 | 3.90 | 1.75 |
| 20 | .0359 | 0.0375 | .035 | 0.0348 | 0.0320 | 0.1610 | 1,020 | 10.4 | 3.09 | 1.50 |
| 21 | .0329 | 0.0344 | .032 | 0.0318 | 0.0285 | 0.1590 | 810 | 13.1 | 2.45 | 1.375 |
| 22 | .0299 | 0.0312 | .028 | 0.0286 | 0.0253 | 0.1570 | 642 | 16.5 | 1.94 | 1.25 |
| 23 | .0269 | 0.0281 | .025 | 0.0258 | 0.0226 | 0.1540 | 509 | 20.8 | 1.54 | 1.125 |
| 24 | .0239 | 0.0250 | .022 | 0.0230 | 0.0201 | 0.1520 | 404 | 26.2 | 1.22 | 1 |
| 25 | .0209 | 0.0219 | .020 | 0.0204 | 0.0179 | 0.1495 | 320 | 33.0 | 0.970 | 0.875 |
| 26 | .0179 | 0.0187 | .018 | 0.0181 | 0.0159 | 0.1470 | 254 | 41.6 | 0.769 | 0.75 |
| 27 | .0164 | 0.0172 | .016 | 0.0173 | 0.0142 | 0.1440 | 202 | 52.5 | 0.610 | 0.6875 |
| 28 | .0149 | 0.0156 | .014 | 0.0162 | 0.0126 | 0.1405 | 160 | 66.2 | 0.484 | 0.625 |
| 29 | .0135 | 0.0141 | .013 | 0.0150 | 0.0113 | 0.1360 | 127 | 83.4 | 0.384 | 0.5625 |
| 30 | .0120 | 0.0125 | .012 | 0.0140 | 0.0100 | 0.1285 | 101 | 105 | 0.304 | 0.5 |
| 31 | .0105 | 0.0109 | .010 | 0.0132 | 0.0089 | 0.1200 | 79.7 | 133 | 0.241 | 0.4375 |
| 32 | .0097 | 0.0102 | .009 | 0.0128 | 0.0080 | 0.1160 | 63.2 | 167 | 0.191 | 0.4063 |
| 33 | .0090 | 0.0094 | .008 | 0.0118 | 0.0071 | 0.1130 | 50.1 | 211 | 0.152 | 0.375 |
| 34 | .0082 | 0.0086 | .007 | 0.0104 | 0.0063 | 0.1110 | 39.8 | 266 | 0.120 | 0.3438 |
| 35 | .0075 | 0.0078 | .005 | 0.0095 | 0.0056 | 0.1100 | 31.5 | 335 | 0.0954 | 0.3125 |
| 36 | .0067 | 0.0070 | .004 | 0.0090 | 0.0050 | 0.1065 | 25.0 | 423 | 0.0757 | 0.2813 |
| 37 | .0064 | 0.0066 | | 0.0085 | 0.0045 | 0.1040 | 19.8 | 533 | 0.0600 | 0.2656 |
| 38 | .0060 | 0.0062 | | 0.0080 | 0.0040 | 0.1015 | 15.7 | 673 | 0.0476 | 0.25 |
| 39 | | | | 0.0075 | 0.0035 | 0.0995 | 12.5 | 848 | 0.0377 | |
| 40 | | | | 0.0070 | 0.0031 | 0.0980 | 9.9 | 1070 | 0.0200 | |
| 41 | | | | 0.0066 | 0.0028 | 0.0960 | | | | |
| 42 | | | | 0.0062 | 0.0025 | 0.0935 | | | | |
| 43 | | | | 0.0060 | 0.0022 | 0.0890 | | | | |
| 44 | | | | 0.0058 | .0020 | 0.0860 | | | | |
| 45 | | | | 0.0055 | .0018 | 0.0820 | | | | |
| 46 | | | | 0.0052 | .0016 | 0.0810 | | | | |
| 47 | | | | 0.0050 | .0014 | 0.0785 | | | | |
| 48 | | | | 0.0048 | .0012 | 0.0760 | | | | |
| 49 | | | | 0.0046 | .0011 | 0.0730 | | | | |
| 50 | | | | 0.0044 | .0010 | 0.0700 | | | | |

*Note:* The present trend, especially for sheet and strip, is to quote thickness as decimal or fraction of an inch rather than gage number. ANSI Standard preferred thicknesses have been adopted. These preferred sizes for thickness of uncoated sheet, strip, and plate under 0.25 in. are as follows: .224, .220, .180, .160, .140, .125, .112, .100, .090, .080, .071, .063, .056, .050, .045, .040, .036, .032, .028, .025, .022, .020, .018, .016, .014, .012, .011, .010, .009, .008, .007, .006, .005, .004.

**KEY:** (1) Manufacturer's standard for hot- and cold-rolled uncoated carbon steel sheet and most alloy steel sheet.
(2) U.S. Standard for cold-rolled steel strip and stainless and nickel alloy sheet.
(3) Birmingham or Stub for hot-rolled carbon and alloy steel strip and tubing.
(4) Washburn and Moen, Roebling, or U.S. Steel for steel wire.
(5) American wire gage or Brown and Sharpe for non-ferrous wire, sheet, and strip.

Dimensions in approximate decimals of an inch.

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**TABLE E.6 Properties of Typical Gaseous and Liquid Commercial Fuels***

| *Gaseous fuels* | *Composition, percent by volume* | | | | | | | | *Mol wt of fuel* | *Theor. air/fuel ratio by wt* | *Higher heating value, Btu/lb$_m$* | *Density, lb$_m$/ft$^3$* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_2$ | $N_2$ | $O_2$ | $CH_4$ | $CO$ | $CO_2$ | $C_2H_4$ | $C_6H_6$ | | | | |
| Blast furnace gas | 1.0 | 60.0 | — | — | 27.5 | 11.5 | — | — | 29.6 | 0.667 | 1,170 | .075 5[a] |
| Blue water gas | 47.3 | 8.3 | 0.7 | 1.3 | 37.0 | 5.4 | — | — | 16.4 | 3.759 | 6,550 | .042 2[a] |
| Carb. water gas | 40.5 | 2.9 | 0.5 | 10.2 | 34.0 | 3.0 | 6.1 | 2.8 | 18.3 | 7.299 | 11,350 | .046 6[a] |
| Coal gas | 54.5 | 4.4 | 0.2 | 24.2 | 10.9 | 3.0 | 1.5 | 1.3 | 12.1 | 10.87 | 16,500 | .031 1[a] |
| Coke-oven gas | 46.5 | 8.1 | 0.8 | 32.1 | 6.3 | 2.2 | 3.5 | 0.5 | 13.7 | 17.24 | 17,000 | .032 6[a] |
| Natural gas (15.8% $C_2H_6$) | — | 0.8 | — | 83.4 | — | — | — | — | 18.3 | 17.24 | 24,100 | .045 1[a] |
| Producer gas | 14.0 | 50.9 | 0.6 | 3.0 | 27.0 | 4.5 | — | — | 24.7 | 14.29 | 2,470 | .063 6[a] |

| *Liquid commercial fuels* | *Vapor* | | *Gravity, API, 60°F* | *Distillation* | | | *Flash point, °F* | *Viscosity, centi-stokes, 100°F* | *Mol wt of fuel* | *Theor. air/fuel ratio by wt* | *Higher heating value, Btu/lb$_m$* | *Density, lb$_m$/ft$^3$* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $c_p$, 60°F | $c_p/c_v$, 60°F | | 10%, °F | 90%, °F | End point, °F | | | | | | |
| | (approximately) | | | | | | | | | | | |
| Gasoline | 0.4 | 1.05 | 63 | 121 | 320 | 397 | 0 | — | 113 | 14.93 | 20,460 | 43.8[b] |
| Gasoline | 0.4 | 1.05 | 63 | 118 | 330 | 410 | 0 | — | 126[c] | 14.97 | 20,260 | 46.1[b] |
| Kerosene | 0.4 | 1.05 | 41.9 | 370 | 510 | 546 | 130 | — | 154[c] | 14.99 | 19,750 | 51.5[b] |
| Diesel oil (1-D) | 0.4 | 1.05 | 42 | — | 550 | — | 100 | 1.4–2.5 | 170 | 15.02 | 19,240 | 54.6[b] |
| Diesel oil (2-D) | 0.4 | 1.05 | 36 | — | 540–576 | — | 125 | 2.0–5.8 | 184 | 15.06 | 19,110 | 57.4[b] |
| Diesel oil (4-D) | 0.4 | 1.05 | — | — | — | — | 130 | 5.8–26.4 | 198 | 14.93 | 18,830 | 59.9[b] |

[a]Based on dry air at 25°C and 760 mm Hg.
[b]Based on $H_2O$ at 60°F, 1 atm ($\rho$ = 62.367 lb$_m$/ft$^3$).
[c]Estimated.

*Abridged from: "Engineering Experimentation", G.L. Tuve and L.C. Domholdt, McGraw-Hill Book Company, 1966; and "The Internal Combustion Engine", 2nd ed., C.F. Taylor and E.S. Taylor, International Textbook Co., 1961.

*Note:* For heating value in J/kg, multiply the value in Btu/lb$_m$ by 2324. For density in kg/m$^3$, multiply the value in lb/ft$^3$ by 16.02.



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**TABLE E.7 Combustion Data for Hydrocarbons***

| *Hydrocarbon* | *Formula* | *Higher heating value (vapor), Btu/lb$_m$* | *Theor. air/fuel ratio, by mass* | *Max flame speed, ft/sec* | *Adiabatic flame temp (in air), °F* | *Ignition temp (in air), °F* | *Flash point, °F* | *Flammability limits (in air), % by volume* | |
|---|---|---|---|---|---|---|---|---|---|
| **PARAFFINS OR ALKANES** | | | | | | | | | |
| Methane | $CH_4$ | 23875 | 17.195 | 1.1 | 3484 | 1301 | gas | 5.0 | 15.0 |
| Ethane | $C_2H_6$ | 22323 | 15.899 | 1.3 | 3540 | 968–1166 | gas | 3.0 | 12.5 |
| Propane | $C_3H_8$ | 21669 | 15.246 | 1.3 | 3573 | 871 | gas | 2.1 | 10.1 |
| *n*-Butane | $C_4H_{10}$ | 21321 | 14.984 | 1.2 | 3583 | 761 | −76 | 1.86 | 8.41 |
| *iso*-Butane | $C_4H_{10}$ | 21271 | 14.984 | 1.2 | 3583 | 864 | −117 | 1.80 | 8.44 |
| *n*-Pentane | $C_5H_{12}$ | 21095 | 15.323 | 1.3 | 4050 | 588 | < −40 | 1.40 | 7.80 |
| *iso*-Pentane | $C_5H_{12}$ | 21047 | 15.323 | 1.2 | 4055 | 788 | < −60 | 1.32 | 9.16 |
| Neopentane | $C_5H_{12}$ | 20978 | 15.323 | 1.1 | 4060 | 842 | gas | 1.38 | 7.22 |
| *n*-Hexane | $C_6H_{14}$ | 20966 | 15.238 | 1.3 | 4030 | 478 | −7 | 1.25 | 7.0 |
| Neohexane | $C_6H_{14}$ | 20931 | 15.238 | 1.2 | 4055 | 797 | −54 | 1.19 | 7.58 |
| *n*-Heptane | $C_7H_{16}$ | 20854 | 15.141 | 1.3 | 3985 | 433 | 25 | 1.00 | 6.00 |
| Triptane | $C_7H_{16}$ | 20824 | 15.141 | 1.2 | 4035 | 849 | — | 1.08 | 6.69 |
| *n*-Octane | $C_8H_{18}$ | 20796 | 15.093 | — | — | 428 | 56 | 0.95 | 3.20 |
| *iso*-Octane | $C_8H_{18}$ | 20770 | 15.093 | 1.1 | — | 837 | 10 | 0.79 | 5.94 |
| **OLEFINS OR ALKENES** | | | | | | | | | |
| Ethylene | $C_2H_4$ | 21636 | 14.807 | 2.2 | 4250 | 914 | gas | 2.75 | 28.6 |
| Propylene | $C_3H_6$ | 21048 | 14.807 | 1.4 | 4090 | 856 | gas | 2.00 | 11.1 |
| Butylene | $C_4H_8$ | 20854 | 14.807 | 1.4 | 4030 | 829 | gas | 1.98 | 9.65 |
| *iso*-Butene | $C_4H_8$ | 20737 | 14.807 | 1.2 | — | 869 | gas | 1.8 | 9.0 |
| *n*-Pentene | $C_5H_{10}$ | 20720 | 14.807 | 1.4 | 4165 | 569 | — | 1.65 | 7.70 |
| **AROMATICS** | | | | | | | | | |
| Benzene | $C_6H_6$ | 18184 | 13.297 | 1.3 | 4110 | 1044 | 12 | 1.35 | 6.65 |
| Toluene | $C_7H_8$ | 18501 | 13.503 | 1.2 | 4050 | 997 | 40 | 1.27 | 6.75 |
| *p*-Xylene | $C_8H_{10}$ | 18663 | 13.663 | — | 4010 | 867 | 63 | 1.00 | 6.00 |
| **OTHER HYDROCARBONS** | | | | | | | | | |
| Acetylene | $C_2H_2$ | 21502 | 13.297 | 4.6 | 4770 | 763–824 | gas | 2.50 | 81 |
| Naphthalene | $C_{10}H_8$ | 17303 | 12.932 | — | 4100 | 959 | 174 | 0.90 | 5.9 |

*Based largely on: "Gas Engineers' Handbook", American Gas Association, Inc., Industrial Press, 1967.

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*Note:* For heating value in J/kg, multiply the value in Btu/lb$_m$ by 2324. For flame speed in m/s, multiply the value in ft/s by 0.3048.

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